ANTICIPATING FUTURES: AN OPERATIONS RESEARCH MODEL FOR STATEWIDE POSTSECONDARY EDUCATION PLANNING

BY

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL
OF THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1980

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ACKNOWLEDGEMENTS

I wish to thank the members of my doctoral committee, Dr. James L. Wattenbarger, Dr. Ralph B. Kimbrough, and Dr. James F. Burns, for their constant guidance and support. The committee's efforts improved considerably the theoretical base, the model developed from it, and the manner in which it was presented.

Thanks are extended to the staffs at the Florida Department of Education, the University of Florida College of Nursing, and the Bureau of Economic and Business Research for their assistance. In particular, I thank Dr. Wallace E. Bell of the Division of Community Colleges and Dr. James K. Umholtz of the Office of Educational Facilities Construction.

I am appreciative of the financial support I received from the Florida Community Junior College Inter-Institutional Research Council, the Department of Educational Administration, and the Florida Institute for Educational Linkage Development during the period of graduate work.

Special thanks are extended to Deborah Hill for her excellent job of typing and proofing the dissertation.

Lastly, appreciation of the unique role my family has played throughout my graduate studies is acknowledged. To my wife, Lorrinda Gail, I bestow my greatest thanks of all.

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Abstract of Dissertation Presented to the Graduate
Council of the University of Florida in Partial Fulfillment
of the Requirements for the Degree of Doctor of Philosophy

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August, 1980

Chairman: Dr. James L. Wattenbarger
Major Department: Educational Administration and Supervision

This study presents the results of an initial research effort in the development of a statewide planning model for public postsecondary education. A prototype linear programming model was developed as a tool to assist state postsecondary education planners maximize selected system-wide policy objectives. The model could be used to generate alternative futures which could aid state-level planners in formulating strategies to adapt to, prevent, or achieve a possible system future. The focus of the model was not to predict the future, but rather to facilitate anticipation of many futures and preparation of alternative strategies as system conditions such as enrollment, social demands for educational opportunities, resource allocation patterns, and manpower requirements change.

Limited application of the model was accomplished using the registered nurse programs offered in Florida's community colleges. A set of three manpower requirement scenarios for community college registered nurse program graduates by geographic area was devised for 1985. Each of the three manpower scenarios was applied to two different community college 1985 scenarios, one which allowed the community colleges complete freedom to respond to the manpower scenarios, the other was constrained by trend analysis forecasts of student demand, available facilities, and appropriations. From the analysis of the resulting six futures, strategies were suggested for the community college system to prevent an anticipated 1985 shortage of registered nurses in Florida.

CHAPTER 1
INTRODUCTION

With the evolution of a technologically complex society, traditional methods of planning, decision-making, and problem solving have become inadequate tools for the education administrator. It has become evident that exclusively verbal descriptions of complex systems and their interactions have resulted in generalizations which have presented problems for comparison, analysis, and evaluation. Numerous studies have documented the increasing importance of quantitative methods in several areas of administrative endeavor (Banghart, 1969; Bertalanffy, 1956, Churchman, Ackoff, & Arnoff, 1957, Goodlad, O'Toole, & Tyler, 1966, Hall, 1962, Optner, 1965, Van Dusseldorp, Richardson, & Foley, 1971, Wiener, 1950, 1961). Three principle areas in which quantitative techniques have been applied include: (1) planning, (2) organizational control and the decision-making process, and (3) the analysis of how organizational systems work and how their different parts or subsystems are interrelated (Bell, 1977, Martino, 1972; Optner, 1975). Though these three categories are hardly mutually exclusive, the fundamental utility of the study relates to the planning area.

Planning has been characterized as being a continuous activity. Churchman (1968) expanded on this notion and stated that planning was 'a series of approximations in which each approximation in principle is better than its predecessor' (p. 145).

Ackoff (1970) viewed planning as anticipatory decision-making, made necessary because of the interdependence of decisions, and future oriented by nature. In Ackoff's words,

> planning is a process that involves making and evaluating each of a set of interrelated decisions before action is required, in a situation which it is believed that unless action is taken a desired future state is not likely to occur, and that, if appropriate action is taken, the likelihood of a favorable outcome can be increased. (p. 4)

The determination of the possible 'future states' of a system is accomplished through the development of a methodology and the resultant system model. Optner defined methodology as a 'logically and procedurally organized arrangement of steps' (1965, p. 16). The methodology used for planning in futures research is called simply the forecast. Amara and Salancik defined forecast as a 'probabilistic, reasonably definite statement about the future which is based upon an evaluation of alternatives' (1972, p. 112). Joseph (1974) offered a further elaboration and characterized a forecast as

> a formalized and systemic methodology for determining future possibilities that allows us to move beyond pure speculative conjecture about the future. It is a system of quantified estimates of changes and alternatives. The key is that a forecast uses a system of logic and yields reproducible and relatively consistent results independent of the forecaster. A forecast therefore rests upon an explicitly stated set of logical assumptions,

> data and relationships, and therefore differs from opinion and prophesy. (p. 4)

Different planning orientations or planning approaches have been devised that incorporate different forecasting techniques. The three major approaches toward planning for the future in education have been identified by Ziegler (1972) as preventive, adaptive, and inventive. The preventive approach has been the most widely used approach. The approach is characterized by a lack of effort to examine the unanticipated consequences of intervention and to relate forecasts to a comprehensive analysis of other interacting variables. The future is essentially considered an extrapolation of the past. When utilizing the adaptive approach, immediate actions are taken to adapt to the forecasts made. The third planning approach is the inventive approach. One principal characteristic of the inventive approach is the recognition that the future is not a predetermined extrapolation of the past, but rather consists of an array of alternative futures which can be explained in some detail. Another characteristic is the recognition that it is both possible and desirable to intervene creatively in the present to bring about a more desirable future (p. 8).

The planning approach, whether it be preventive, adaptive, or inventive has been one basis used to differentiate short-, medium-, and long-range planning. Table 1, adapted from Jarupanich (1975, p. 28), presents a more complete breakdown of planning type by planning characteristic.

Just as there have been different planning types and different general planning approaches devised, different planning methodologies or forecasts have been developed also. Jantsch (1967, p. 15) has grouped the many available futures research techniques into four broad categories, intuitive, exploratory, normative, and feedback. Though other classification schemes have been devised (Joseph, 1974, Martino, 1972), the groupings offered by Jantsch facilitated the discussion of the procedures used throughout the study

Table 1
Characteristics of Long-, Medium-, and Short-Range Planning

Planning Type	Planning Characteristics				
	Planning Objectives	Planning Outcomes	Planning Approach	Planning Purpose	Planning Criteria
Long-Range	Ideals	Policies	Inventive	Establish Direction	Normative or Policy Planning
Medium-Range	Objectives	Programs	Adaptive	Establish Strategies	Strategic Planning
Short-Range	Goals	Methods and Procedures	Preventive	Allocate Resources	Tactical Planning

In Jantsch's scheme, intuitive thinking has been used as one forecasting method. Jantsch described these intuitive techniques as the gracious gift of the subconscious mind in return for the previous labors of the conscious mind' (1967, p. 133). Exploratory methods extend the past or current patterns into the future and attempt to create an awareness of the demands which these patterns are "hypothesized to create" (Heinmiller, 1977, p. 14). Normative techniques begin by determining future needs or goals and then, by working backward to the present, a path for the attainment of the stated goals is formulated (Sage & Chobot, 1974, p. 152). Feedback or cybernetic techniques integrate the normative and exploratory methods to create a future state, modifications are incorporated into the scheme as additional information is obtained (Jantsch, 1967, p. 113).

In this study the medium- and long-range planning objectives of an educational system were incorporated into a system model that facilitated investigating a series of forecasts, any one of which could represent the eventual future. Emphasis was on taking the inventive approach toward the future. The system model combined both exploratory and normative methods to create a future state and was rooted in general systems theory.

In brief, general systems theory was described by Miller (1965) as "a set of related definitions, assumptions, and propositions which deal with reality as an integrated hierarchy of organizations of matter and energy" (p. 193). All systems display certain properties, and although there have come to exist rather elaborate listings of these properties (see Miller, 1978), a few of the more basic Immegart (1969) summarized as follows.

> 1. All systems exist in time-space.
>
> 2. All systems tend toward a state of randomness and disorder, the ultimate of which is entropy, or inertia.
>
> 3. All systems have boundaries, which are more or less arbitrary demarcations of that included within and that excluded from the system.
>
> 4. All systems have environment, which is everything external to (without the boundary of) the system.
>
> 5 All systems have factors that affect the structure and function of the system. Factors within the system are variables, factors in the system's environment are parameters.
>
> 6 All but the largest systems have suprasystems.
>
> 7 All but the smallest systems have subsystems. (p. 167)

A number of approaches have evolved that have applied concepts of general systems theory. The major approaches stated by Immegart and Pilecki (1973) have included: (1) cybernetics, (2) holism, (3) output analysis, (4) systems design, (5) information theory, (6) systems analysis, (7) systems engineering, (8) mathematical programming, (9) computer science, and (10) operations research (p. 9). Utilization of the operations research approach was made in the study.

Operations research (OR) has somewhat different objectives than does general systems theory. Moder and Elmaghraby (1978) stated the different aims of each in the following manner:

> OR tends to be concerned with problems which can be represented by mathematical models, which, in turn, can be analytically studied and optimized. Systems theory, on the other hand, although formed

> in nature, is concerned with problems of greater complexity, and is more global and abstract in its approach. Its components may consist of mathematical models, but may also incorporate social and biological factors which have not been successfully quantified. OR tends to be mostly concerned with smaller scale problems of existing systems, as contrasted with systems theory which usually connotes a larger and more encompassing perspective of new systems. (pp. xiii-xiv)

In OR, the terms model and model building have been defined as the structure and the act of formulating the structure of some specific concrete system. Dantzig (1963) stated that "model building refers to the process of putting together of symbols representing objects according to certain rules, to form a structure, the model, which corresponds to a system under study in the real world" (p. 6).

Any OR model can be interpreted as being a forecast of many possible futures. Brown (1978) stated that OR

> is concerned with models that demonstrate the consequences of . . . alternatives . . . based on current information about the significant factors involved. While some of the pertinent information is observable and measurable, there is usually a time lag between the time when a decision is taken and the time when its consequences become apparent. During that time lag some of the information may change. Thus, the decision is based, not on observable information, but on a forecast. (p. 3)

By varying the parameters of an OR model an array of possible futures can be generated. Strategies can then be developed to deal with each future that has been generated. Strategies are dependent upon the planning approach that has been taken, either preventive, adaptive, or inventive.

Operations research is characterized by the application of the scientific approach, scientific tools, and scientific techniques to decision-making problems that involve the operation of an organizational system. Obtaining optimum solutions to the problems is the primary goal (Daellenbach & Bell, 1970, p. 1).

Operations research techniques that have been used extensively include: (1) game theory, (2) queueing theory, (3) network analysis, (4) simulation, (5) dynamic programming, (6) inventory theory, (7) decision analysis, (8) integer programming, (9) nonlinear programming, and (10) linear programming (see Hillier & Lieberman, 1974).

Of the many techniques of OR, linear programming has been the most widely used. Simply put, linear programming "is concerned with describing the interrelations of the components of a system" (Dantzig, 1963, p. 6). The impact of linear programming has been succinctly stated by Hillier and Lieberman (1974):

> Many people rank the development of linear programming among the most important scientific advances of the mid-twentieth century, and we must agree with this assessment. Its impact since just 1950 has been extraordinary. Today it is a standard tool that has saved many thousands or millions of dollars for companies or businesses of even moderate size in the industrialized countries of the world, and its use in other sectors of society is rapidly spreading. (p. 15)

In the study, the linear programming OR technique was used to incorporate possible future statewide needs and state-level policies into a prototype model of a statewide public postsecondary education system. Different scenarios were generated by changing policies and other model parameters thereby facilitating the development of alternative strategies to adapt to, prevent, or achieve each possible system future.

The Problem

Statement of the Problem

The problem of the study was to develop a prototype linear programming model that will assist state public post-secondary education planners in maximizing selected or multiple system-wide policy objectives. The model was used to generate alternative futures which could aid state-level planners in formulating strategies to adapt to, prevent, or achieve a possible system future. The focus of the model was not to predict the future, but rather to facilitate anticipation of many futures and the preparation of alternative strategies as system conditions such as enrollment, manpower requirements, resource allocation patterns, and social demands for educational services change. Ultimate objectives of research such as this would include the following:

1. Establishment of long-range plans and priorities.
2. Coordination of medium- and long-range planning.
3. Program evaluation as a function of objectives, costs, and benefits.
4. Resource allocation as a function of system-wide needs and resources.
5. Identification and analysis of alternative methods of achieving system goals and anticipating different system futures

Delimitations

The following were observed in the conduct of the study.

1. The development of the prototype model was confined to the analysis of a single occupational program.
2. A second delimitation is that the model application was restricted to the state of Florida.
3. The planning horizon was limited to five years. Various scenarios were created for the year 1985 and the model was used to assist the formulation of system strategies in response to the several scenarios.
4. If models are to simulate the entire public postsecondary education system of a state within various time, cost, and utility constraints, a system-wide management information system (MIS) becomes a necessity. In other words, standardized definitions of all data elements along the lines of the data element dictionary developed by the National Center for Higher Education Management Systems (Goddard, Martin, & Romney, 1973) must be formulated and each postsecondary institution in the state must submit requested MIS data in terms of the standardized definitions. In Florida, no such MIS has been developed. The objective of the study, however, was not the development of a standardized MIS. An MIS has been developed and used since 1969 to collect Florida community college system data. In view of this, a fourth delimination was that only Florida community college data were used for the public postsecondary education dimension of the prototype model.

Limitations

Although the prototype model developed in the study was restricted to a single occupational program and to the public community college system of the state of Florida, the model may be generalized to other programs, entire postsecondary education systems, and to other states provided certain criteria are met. First, postsecondary education commissions must have the authority and responsibility to collect all relevant data from all postsecondary education institutions in the state on a regular basis. A comprehensive postsecondary education system MIS simply must exist. It should require little change or maintenance from year to year and include the maximum amount of pertinent information available. Secondly, the model can be generalized to include other programs existing in postsecondary education institutions to the degree that these programs can be related to particular occupations. A study by Folger and Nam (1964) demonstrated the difficulty of relating education preparation to occupation and that in the United States the trend was toward increasing uncertainty concerning this relationship. Thirdly, the model is dependent on general manpower and economic variables and the breakdown of these variables by geographic areas of a state. Fourthly, generalizability will depend on the extent that the problem studied satisfies the theoretical assumptions of linear programming and modeling.

Justification

One major factor impelling the study centers on the investigation of the following proposition: Since OR has proven itself in industry, similar applications to education can result in more effective and efficient strategies being devised to attain educational goals and meet society's needs given a set of constraints. Coombs and Hallak (1972) offered the following comment on the need to apply a spectrum of different planning tools and include more factors to improve system efficiency and effectiveness:

> Planners and administrators will in the future have to take into greater account the economic aspects involved in their plans and explore every means of improving the efficiency of their educational system so as to get the best value from existing resources. (p. 5)

The application of operations research (OR) models in educational planning has increased since 1970. McNamara (1973) cited several reasons for the expanded interest:

> During the past few years there has been a significant increasing interest placed on an examination of the extent to which models developed in operations research, management science and econometrics might be used to improve the methodology and procedures currently employed in various areas of public sector planning and policy analysis. This type of inquiry has led some social scientists and public administrators to conclude that the problem solving approach . . . can be used collectively to develop better measures for socioeconomic planning and resource allocation. (p. 19)

Yet, OR models have had difficulty providing usable results. According to Johnstone (1974),

> models of many types have been developed over recent years for use in educational planning . . . very few . . . have given results which could be helpful to an educational planner. (p. 195)

One reason has been the limited scope of past models. Relevant properties of the system under study failed to be represented in the model because of the difficulty of quantifying data. Areas which lacked any clear objective function were avoided (Page, Jarjoura, & Konopka, 1976). OR models in education, however, have been particularly useful when the planning objective was optimum resource allocation, meeting manpower requirements, satisfying social demands for education, or minimizing the social cost-benefit ratio. Panitchpakdi (1977, p. 339) stated that the typical model has educational targets determined by only one of the above possibilities. The model developed in the study integrated aspects of each in order to devise a more realistic representation of an educational system.

Few operations research models have utilized the inventive futures approach for medium- or long-range planning (Hufner, 1968, Johnstone, 1974; McNamara, 1973). The study was therefore heuristic.

Extending OR models designed for a subsystem of a state postsecondary education system to the entire system is a function of information availability and standardization (Harcleroad, 1971, pp 34-38; Krause, 1970, pp. 86-91). The study, therefore, demonstrated the need that a statewide postsecondary education MIS exist.

Assumptions

For the purposes of this study a number of assumptions were made. The first set of assumptions relates to the formulation of the linear programming model. In order for the system to have been represented by a linear programming model, assumptions of proportionality, additivity, divisibility, nonnegativity, and deterministic problem nature had to be made. Chapter II includes a brief explanation of these basic linear programming assumptions.

The second set of assumptions, adapted from Sachs (1977, pp. 165-166), relates to the general theory of modeling. The assumptions follow.

1. The model includes all relevant properties of the reality.
2. Model properties correspond to real world properties.
3 All relevant properties of the real world can be expressed mathematically.

In light of the model assumptions, the single most pervasive assumption of the study was to "neglect the negligible." Dantzig (1963) confronted the issue as follows:

> It is important to realize in trying to construct models of real-life situations, that life seldom, if ever, presents a clearly defined linear programming problem, and the simplification and neglect of certain characteristics of reality are as necessary in the application of linear programming as they are in the use of any scientific tool in problem solving. (p 7)

Definition of Terms

Community college. An educational institution supported by public tax funds, governed by a politically appointed or elected board, and which offers courses and/or programs confined to the first two years of post high school education.

FTE student Full-time equivalent student Annualized for Florida community colleges, 30 semester hours equal one FTE student.

Futures. Any of a number of probabilistic, reasonably definite statements about the future state of a system given a set of initial conditions specified at some earlier point in time.

Futures research. Investigations which enhance the understanding of future consequences of current developments.

Linear programming. A "mathematical tool for obtaining optimum solutions that do not violate . . . constraints, that cannot have negative activities, that require linearly proportional relationships, and that account for all inputs and outputs within the system" (Greenberg, 1976, p. 5).

Manpower. The number of persons employed in a given occupation as function of geographical area.

Model. A mathematical representation of a system to be utilized for the purposes of creating alternative future system states and facilitating the formulation of strategies to prevent, achieve, or adapt to each.

MPSX. An abbreviated form of Mathematical Programming System Extended, an IBM computer code used for linear programming and closely related techniques (IBM, 1972).

OR. An abbreviation for operations research, it is an approach used to assist in solving management problems through interpretation and use of available data (Schroeder & Adams, 1976, p. 118).

Public postsecondary education. Education offered by public four-year and graduate institutions, community colleges, technical institutes, junior colleges, area vocational schools, and postsecondary vocational schools. Referred to, hereafter, as simply postsecondary education (U.S. Senate, 1972, p. 89).

Registered nurses. This "group includes occupations concerned with administering nursing care to the ill or injured. Includes nursing administration and instruction, and public health, industrial, private duty, and surgical nursing. Licensing or registration is required" (U. S. Department of Labor, 1977, p. 56). Abbreviated as RN.

Scenario. A combination of a set of model parameters or forecasts that effect the future state of a system.

Sensitivity analysis. The analysis of the affect on the optimal solution of a linear programming model as model parameters are changed.

State postsecondary education commission. A state agency legally charged with supervising, evaluating, organizing, regulating, or compiling the policies for a state postsecondary education system for the purposes of planning and coordination, referred to as the "1202 commission."

Statewide planning. "The identification of key problems, the accumulation of accurate data about those problems, the analysis of their interrelationships, the examination of alternatives which might emerge out of present conditions, the evaluation of the probable consequences of introducing new variables, the choice of the most desirable basic goals, a plan for implementing these goals, and a constant feedback system for periodically reevaluating both the goals selected and the appropriate means used to attain them" (Lyddy, 1975, p. 26).

System. A set of interrelated activities, units, or variables (Miller, 1978, p. 16).

Procedures

The general procedures outlined below and detailed in subsequent sections were followed in the study: (1) review of related literature, (2) model development, and (3) development of alternative future scenarios and possible system strategies in response to scenario conditions.

Phase I -- Literature Review

Literature reviewed related to statewide postsecondary education planning and research, operations research as a planning tool, linear programming, and linear programming computer codes. Sources included books, monographs, and articles identified through the following indices: Current Index of Journals in Education, Dissertation Abstracts International, and the Education Index. Articles taken from journals outside education came primarily from the following: Long Range Planning, Management Science, Operations Research, and Socio-Economic Planning Science.

Review of the rise of operations research (OR) as a planning tool included a survey of selected mathematical programming techniques and probabilistic models that have been developed. Previous applications of OR techniques in postsecondary education at the state and national levels were discussed.

Description of the general characteristics of linear programming included a discussion on sensitivity analysis. How linear programming was used to create alternative futures was also presented

The final section of the literature review included a general survey of linear programming computer codes. IBM's MPSX code was also introduced.

Phase II -- Model Development

The development of the model was accomplished through the application of a series of steps recommended by Banghart (1969, p. 297).

1. Outline the problem.
2. Determine the constraints.
3. Put the problem in mathematical form.
4. Satisfy the linear programming assumptions.
5. Formulate the objective function.
6. Determine the optimal solution.
7. Perform a sensitivity analysis.

Step 1. The outline of the problem has been presented in Chapter I. Rationale for selecting the registered nurse program in Florida's community college system as part of the general problem delimitation was determined and justified through the literature review and the analysis of Florida's community college MIS.

Step 2 and Step 3. Primary constraints and functional constraint equations were determined by Florida community college system policies and the data available through the Division of Community Colleges. Data for manpower and economic constraints were extracted mainly from U. S. government publications and the Florida Statistical Abstract. Whenever possible, existing variable values projected to the year 1985 were used. In the event no such information was available for a variable, the simple trend analysis or the double exponential smoothing technique was used to estimate the variable value for 1985.

Step 4. It was assumed that the model and model variables satisfied the assumptions of linear programming.

Step 5. From the wide range of objective functions that could have been formulated, the objective function selected was to maximize system-wide enrollment.

Step 6 and Step 7. MPSX was the linear programming computer code used to determine the existence of an optimal solution. A sensitivity analysis was also accomplished using various 1985 RN manpower requirements scenarios as described in Phase III.

Phase III -- Alternative Future Scenarios and System Strategies

Limited application of the model was accomplished using the registered nurse, RN, programs offered in Florida's community college system. A set of three future scenarios for 1985 based on trends identifiable in 1980 was devised to determine the 1985 manpower requirements for community college RN program graduates by state geographic area. Each of the three manpower scenarios was applied to two different community college 1985 scenarios.

The first community college RN program scenario, Series I, was a normative scenario which described 1985 community college RN programs as having the freedom to satisfy the manpower requirements optimally. By the application of three RN manpower scenarios, parameter ranges were determined for the resulting ideal community college RN program scenario futures.

The second community college RN program scenario, Series II, was an exploratory scenario which described the 1985 community college RN program condition based on 1980 trends. Again, parameter ranges for the resulting straight-line projection scenario futures were determined by the application of the three RN manpower scenarios.

In sum, six different 1985 futures were investigated. The object of the analysis was to compare Series I and Series II futures to determine the primary and secondary constraints in the Series II futures that prevented the community college RN programs in 1985 from attaining the ideal Series I futures. Strategies were then suggested from the results.

Organization of the Research Report

The research report contained the following chapters.

Chapter I. An introduction to the study, including a statement of the problem with delimitations, limitations, and justification for the study, comprise this chapter. Assumptions are also stated, terms defined, and procedures described.

Chapter II. A review of the related literature is made in Chapter II. The literature on statewide postsecondary education planning and research and general operations research techniques is reviewed. A general survey of linear programming is presented emphasizing the simplex method of solving linear programs and sensitivity analysis. IBM's MPSX computer code is also introduced.

Chapter III: The model development is presented in this chapter.

Chapter IV: A linear programming prototype model is developed dealing with possible state-level policies and needs as they relate to one occupational program offered in Florida's community college system. Data for the model are presented and analyzed. A sensitivity analysis of the model is also included in the chapter. Scenarios depicting conditions affecting Florida's community college system in 1985 are presented. Possible system strategies for each future described by the scenarios are suggested.

Chapter V: In the final chapter, a summary, conclusions, and implications of the study are presented. In addition, directions for future research are suggested.

CHAPTER II
A SELECTIVE REVIEW OF RELATED LITERATURE

Introduction

In the preceding chapter a general survey of reasons that necessitated the use of increasingly qualitative methods for long-range educational planning was presented. By utilizing the techniques of operations research (OR), it was contended that a number of reasonable postsecondary education futures could be generated and then used to aid the development of planning strategies that either adapt to, prevent, or achieve each possible system future. Reviewed in this chapter is material more directly related to the precise topic explored by the study, the development of a linear programming model delimited to a single occupational program offered in Florida community colleges that can be used to measure system responses to various future conditions.

Accordingly, the review of literature was divided into three major segments: Operations Research, Macro Educational Planning Models, and Linear Programming and the MPSX Code. First the development of operations research is presented along with the general characteristics of mathematical programming, the category of OR techniques into which linear programming falls. Next, background information on the rise of OR techniques in system-wide educational planning is given. Several macro models are reviewed followed by a critique of the use of models in educational planning. Finally the characteristics, assumptions, and utility of linear programming models are briefly reviewed and the MPSX computer code used in the study is explained.

Operations Research

Development

As an organized activity in the United States, operations research (OR) began with the establishment of the Operations Research Society of America in 1952. The origin of OR, however, has generally been attributed to teams of military scientists working in Great Britain during World War II on strategic and tactical military problems (Moder & Elmaghraby, 1978, p. ix).

Prior to 1962, information found in the literature on OR is scarce. Indeed, between 1957 and 1962, less than a half dozen books on OR were published in the United States. Books on OR since 1962 numbered in the hundreds and the application of OR techniques has expanded from just the military area to include the social sciences, government, business, economics, the natural sciences, engineering, and mathematics (Moder & Elmaghraby, 1978, pp. ix-xi).

The rise of OR during this period has been attributed to two primary factors. The first was the development of the theoretical foundation of several OR techniques. Hillier and Lieberman (1974) stated that "many of the standard tools of operations research, e.g., linear programming, dynamic programming, queueing theory, and inventory theory, were relatively well developed before the end of the 1950's" (p. 3). The second factor involved the invention of the electronic computer and the rapid advances in computer technology that followed. Indeed, the "development of the electronic digital computers, with their ability to perform arithmetic calculations thousands or even millions of times faster than a human being can, was a tremendous boon to operations research" (Hillier & Lieberman, 1974, p. 3).

The development of OR techniques has paralleled the overall development of OR as a process. In 1956, Ackoff stated at that time each operations researcher's "version of the operations research method (if recorded) would differ in some respects" (1956, p. 265). This led Ackoff to suggest the following six phases for the OR process:

1. Formulating the problem.
2. Constructing a mathematical model to represent the system under study.
3. Deriving a solution from the model. This involves finding the values of the variables that maximize the system's effectiveness.
4. Testing the model and the solution derived from it. This involves evaluating the variables, checking the model's predictions against reality, and comparing actual and forecasted results.
5. Establishing control over the solution. This involves developing tools for determining when

> significant changes occur in the variables and functions on which the solution depends, and determining how to modify the solution in light of such changes.
>
> 6. Putting the solution to work. Implementation. (1956, pp. 265-266)

Schematically, these phases are shown in Figure 1.

The development of OR both from a historical perspective and from the process perspective has been presented. The mathematical programming approach of OR and constructs pertinent to this study are presented next.

Mathematical Programming

Mathematical programming is a deterministic OR approach concerned with deriving optimal solutions to system problems subject to some set of constraints. As a branch of applied mathematics, mathematical programming is rooted in optimization theory. McMillan (1975) stated that the term optimum, in the mathematical sense, seems to have first been used by Leibniz in 1710. With the development of the calculus, Newton and Leibniz made possible the proof that an optimum solution exists, for a class of problems, and provided the means for finding it' (p. ix). Optimization theory grew to where any number of initial conditions or constraints could be incorporated into a problem while the problem remained theoretically solvable.

As a tool for decision-making, mathematical programming began with Dantzig's development of the simplex method of solving linear programming problems in 1947 (see Dantzig,

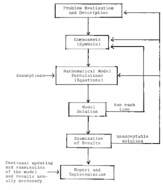
Problem Realization and Description
Components (Symbols)
Assumptions
Mathematical Model Formulations (Equations)
Model Solution
too much time
Examination of Results
unacceptable solution
Continual updating and examination of the model and results usually necessary
Report and Implementation

Figure 1. The OR Process (Adapted from Salkin & Saha, 1975, p. 2).

1948, 1949). A number of prominent mathematicians also contributed significantly to the groundwork theory and extension of mathematical programming. These included Fourier, Gauss, Kantorovich, Koopmans, Kuhn, Tucker, and von Neuman (Dantzig, 1963, p. 13).

A number of mathematical programming techniques have been developed. The most widely used techniques have included linear programming, dynamic programming, integer programming, inventory theory, nonlinear programming, game theory, and network analysis. Linear programming is discussed in a following section. General and specific treatments of all these techniques have been provided in a significant number of texts and articles existing in the literature and the reader is referred to these for elaboration (see Ford & Fulkerson, 1962, Gillett, 1976, Hadley, 1964; Hillier & Lieberman, 1974, Hu, 1965, McKinsey, 1952; Naddor, 1966; Nemhauser, 1966).

A typical mathematical program is depicted in Figure 2. What is desired is the determination of activity levels or variable values that will produce optimal system effectiveness. The effectiveness criterion is an equation measuring the system's performance and is labeled the objective function. By introducing constraints and requiring all variable values to be positive, the basic mathematical program characteristics are complete.

The intent of this section has been to review the development of the mathematical programming OR approach, demonstrate that a variety of mathematical programming

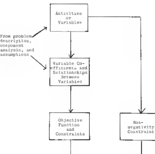
Activities or Variables
From problem description, component analysis, and assumptions
Variable Coefficients and Relationships Between Variables
Objective Function and Constraints
Non-negativity Constraint
Mathematical Program

Figure 2 A Mathematical Program (Adapted from Salkin & Saha, 1975, p. 3).

techniques have been devised, and display the general characteristics of mathematical programs. The succeeding section is to serve as a survey of mathematical programming models developed for regional or national educational systems.

Macro Educational Planning Models

Introduction

The use of mathematical programming OR models as planning tools in education has increased significantly since 1960. In a survey of Organization for Economic Cooperation and Development member countries conducted in 1969, 123 models were found in use or currently under development in 29 different countries (Kahn, 1970). Regardless of apparent widespread acceptance, the use of OR models in postsecondary education has not approached its full potential (Bogard, 1972).

Greater utilization of mathematical programming models paralleled the growth of institutional, regional, and national educational planning. McNamara (1971) explained the increased attention to educational planning as follows:

> The large amount of resources devoted to education and the increasing emphasis on designing educational policy in relation to an overall set of objectives for economic and social development has resulted in the creation of educational plans in virtually all the major nations of the world. (p. 427)

In the United States, the demand for more comprehensive and systematic planning in postsecondary education in the early 1970's has been attributed to the two primary concerns of efficiency and effectiveness. Both issues fall within the purview of mathematical programming models. In a 1972 review of planning models in higher education, Fincher stated that

> the concern for efficiency may be said to reflect the public's concern for accountability. The concern for effectiveness, however, may be said to reflect a deeper, more pervasive concern with the effect that higher education has had on contemporary social, economic, political, and technological issues. The rapid expansion of higher education during the past twenty-five years has not been accompanied by the amelioration of social, economic, and political problems. It is the amelioration of these problems that demands more systematic planning in higher education. (p. 760)

It was the rapid expansion of postsecondary education from World War II through 1970 that was the original reason for increased statewide planning and which spawned an interest in the use of mathematical programming models in education. For example, higher education operating expenditures for the academic year 1972-73 totaled 30.2 billion dollars which represented a fourfold increase from just ten years before. Over this same period, higher education operating costs grew at an annual rate twice that of the gross national product (Halstead, 1974, p. 520). In addition, postsecondary education enrollments had grown to the extent that half of the traditionally college-aged youth were involved in some form of postsecondary education (Gleazer, 1974, p. 6).

These factors and others showed the need for statewide postsecondary education planning and coordination, the urgency of requiring establishment of state-level coordinating boards, and the potential utility of comprehensive OR models in planning. Indeed, McConnell (1962) expressed the holistic view that given limited resources, the entire postsecondary education system of a state must act in collaboration in the pursuit of statewide goals if each institution hopes to have the necessary resources to provide quality education (p. 136). Similar sentiment provided the impetus for creating state-level coordinating commissions for postsecondary education in the United States. In sum, the

> genesis of coordinating boards came from a felt need at the state level to know about budgets, enrollment, academic programs, off-campus programming, and long-term building and new campus plans to assure the best possible allocation of scarce state resources. (McTarnaghan, 1974, p. 23)

McTarnaghan (1974) viewed the following seven developments necessary before statewide postsecondary education commissions could function effectively.

1. An accurate data base with commonly accepted definitions of terms must be maintained on a statewide basis with current accessibility.

2. A management information system must be developed to answer the "what if" questions of contingency planning and to project future needs, resources, utilization, and costs.

3. Management objectives must be established to specify the goals toward which higher education in the state is striving.

4. A state plan for higher education must be developed which can define state-level goals, missions, resource allocations and enrollment projections. It must also portray to the public, to the governor and legislature, and to all interested in higher education, where the

> state is going in terms of higher education, where it should be going, how it should get there, and who is going to do the job.
>
> 5. Clearly defined statements of mission and scope of each institution must be developed to focus upon the way in which each institution will contribute to the specified state goals and objectives. Of significant importance is recognition of the role and mission of the private sector.
>
> 6. A monitoring system must be established to evaluate the progress of each institution in achieving its mission.
>
> 7. Focus must be maintained on desired and needed legislative changes which can strengthen this process and can allocate resources to critical areas of need based on the state plan. (pp 28-29)

The environment necessary before statewide postsecondary education models could be of practical significance was critically dependent both upon the establishment of the state postsecondary education commissions responsible for statewide planning and coordination and the degree to which the commissions met these criteria.

The trend to effective statewide coordination in postsecondary education demonstrated by satisfying the above prerequisites and the use of statewide OR models were developments not embraced by every state or educator. Opponents argued that statewide coordination would discourage institutional uniqueness and excellence, that the 'bureaucracy would take over, that system-wide savings would not materialize, and that demands made by the central staff on each institution would offset the services they provided (Harris, 1974, pp. 39-40).

The issue of how far statewide planning and coordination can go while institutional autonomy and diversity are maintained was addressed in an early study by Moos and Rourke (1959). They warned that 'a tightly coordinated system of higher education can leach quality and originality out of state colleges and universities (pp. 225-226).

Yet, before statewide postsecondary education OR models could realistically be used in increasing system efficiency and effectiveness, the creation of state postsecondary education commissions was necessary. The eventual acceptance of the role of centralized state planning is illustrated by the fact that in 1940 there were 33 states out of 48 that had no state postsecondary education commission and in 1974 there remained only two out of 50 states (Berdahl, pp. 2-3, 1975). Pliner (1966) pinpointed the prevailing orientation of most states in the following terms:

> For the vast majority of states the question of coordination of higher education seems to be settled, and attention is now centered on how to make these agencies [state postsecondary education commissions] more effective in achieving a quality system of higher education that will meet the needs of today and tomorrow. (p. 7)

In 1980 the postsecondary education climate in the United States was not one characterized by the growth and prosperity elements of the period when states first undertook the function of planning and coordinating postsecondary education. Rather, it was characterized by diminishing enrollments, rising costs, and personnel retraction (Purga, 1979, pp. 25-33). It has been predicted that enrollment at this level of education would decline 22% between 1980 and 1990 (Glenny, 1974, p. 60). The task of coordinating postsecondary education systems has been shown to be much more complicated and difficult under steady state, constrained conditions than under growth conditions (Millard, 1974, pp. 36-38)

Strategies developed to cope with the postsecondary education state of affairs during the 1980-1990 decade needed to broaden their scope to include diverse approaches to planning issues. Rodekohr and Rodekohr (1974) stressed that

> if educators are to adapt to and face the challenge of this change, they must acquire a new mode of thinking and planning. The greatest opportunity is to utilize the decline for better education. (p. 621)

Ideally suited for deriving solutions to complex problems of this nature have been the techniques of OR. Indeed, OR mathematical programming models had become even more relevant as a planning tool by 1980. As Schroeder and Adams (1976) suggested,

> it has been said that higher education is entering an era of crises, an economic crisis due to dwindling enrollments and rising costs, a crisis of public confidence, and a crisis of student disenchantment. These crises are making our institutions more difficult to manage, and they call for improved management methods and procedures, a number of which fall within the purview of [operations research]. (p. 117)

McNamara (1973) further displayed the extent OR mathematical programming models could contribute to statewide postsecondary education long-range planning under constraint conditions. He emphasized that

> since mathematical programming allows a planner to view an educational system as a set of input-output or production relationships, which can be controlled in a way that will optimize the use of scarce educational resources, it becomes a valuable technique to generate policy or 'decision-oriented' information (p. 20)

To summarize, an attempt has been made to illustrate that the use of OR models in educational planning has grown significantly since the 1960's. A prerequisite to meaningful statewide postsecondary education modeling in the United States was the creation of statewide postsecondary education commissions. These commissions had to satisfy certain criteria before effective planning and coordination could be realized. The 1960's presented very different circumstances, both endogenous and exogenous to postsecondary education, than had previous years, making the application of OR mathematical programming models more relevant and essential for statewide planning. In the next section, existing macro educational models are reviewed.

Models

Postsecondary education planning models for the purposes of this study have been classified as being either micro or macro models. Micro educational planning models are primarily concerned with institutional operations. The scope of these models is confined to educational units ranging from institutional subdivisions, such as departments, to entire institutions. The only factors detailed relate to the internal characteristics of educational institutions.

Examples of these micro models that have been used extensively are CAMPUS (Judy & Levine, 1965), SEARCE (Keane & Daniel, 1970), RRPM (Hussain, 1971), HELP/PLANTRAN (Midwest Research Institute, 1972), and EFPM (Jones & Updegrove, 1978).

The model developed in the study was, however, a macro educational planning model. Macro models relate entire educational systems to a system external to education such as the economic system. The initial interest in models of this nature began with the development of several such models by the Organization of Economic Cooperation and Development (O.E.C.D.) in the early 1960's (Chirikos & Wheeler, 1968, p. 267). In the United States, the two most widely used national planning models for postsecondary education have been the Federal Planning Model (FPM) (Huckfeldt, Weathersby, & Kirschling, 1973) and the Postsecondary Education Financing Model (PEFM) (National Commission on the Financing of Postsecondary Education, 1973). The model developed in this study was a state-level rather than national model. Since postsecondary education in 1980 was overwhelmingly a state responsibility, an aggregate model at the state-level seemed more appropriate as a planning tool. Models developed by the O.E.C.D. and others were surveyed, however, for relevance to this study.

Macro educational planning models that have integrated educational and economic planning have been divided into three different approaches by Correa (1975). They are:

(1) the manpower approach, (2) the rate-of-return approach, and (3) explicit optimization models (p. 27).

The manpower approach was first used extensively as part of the O.E.C.D.'s Mediterranean Regional Project during the period 1960-75. In brief, the approach

> ascertains future needs for manpower from projections of the growth of the economy and inputs of labor of various skills; the resulting needs of the economy are compared with expected supplies of labor to determine educational production goals. (McNamara, 1971, pp. 427-428)

Criticisms of manpower approach models have included.

1. A lack of attention to productivity changes.
2. Models have been concerned with the labor force required for production whereas available statistics have reported only the labor force being used.
3. Problems of underemployment of labor have not been accounted for since data have not shown the distinction between those who are fully employed and those who are underemployed (Correa, 1969b, pp. 119, 128).

The rate-of-return approach has been used as a second technique to integrate macro educational and economic planning. The underlying assumption of this approach is that only one production technique exists. Models utilizing this assumption force all resource allocations (or system inputs) made to different system units to produce equal gross returns (or system outputs). Correa (1975) stated that in practical applications,

> current educational costs and wages are used to estimate the rate of return to investments in education . . . from this estimate it is concluded that additional investment should be made in the types of education with highest returns (p. 29)

Major weaknesses of this method have included:

1. The approach leaves out supply, demand, and market mechanisms that determine the costs and returns of education.
2. It explicitly excludes the influence on the rate of return of planned changes in the output of the economy and the technology used.
3. If data do not come from an economy in equilibrium, they do not reflect the actual costs and returns of education (Correa, 1975, p. 29).

The third approach used to integrate educational and economic systems for planning purposes has been the use of models that have incorporated characteristics of both the manpower and rate-of-return approaches. These have been labeled optimization models (Correa, 1975, p. 30). Reviews of linear optimization models concerned with macro educational planning have been written by Golladay (1968, pp. 29-68), Johnstone (1974, pp. 177-201), and McNamara (1973, pp. 13-35).

Models and Planning

The orientation of this study toward planning emphasizes that planning for the future of a system encompasses anticipating all possible system futures that have reasonable probabilities of occurring and developing strategies to adapt, prevent, or achieve each future. A future that is seen as desirable results in devising strategies that increase its probability of occurrence. Contingency plans for less desirable futures are also made which in effect prepare the system for the unexpected. Ackoff (1970) expressed this view of planning as well as a word of caution as follows:

> Wisdom is the ability to see the long-run consequences of current actions, the willingness to sacrifice short-run gains for larger long-run benefits, and the ability to control what is controllable and not fret over what is not. Therefore the essence of wisdom is concern with the future. It is not the type of concern with the future that the fortune teller has, he only tries to predict it. The wise man tries to control it.
>
> Planning is the design of a desired future and of effective ways of bringing it about. It is an instrument that is used by the wise, but not by the wise alone. When conducted by lesser men it often becomes an irrelevant ritual that produces short-run peace of mind, but not the future that is longed for. (p. 1)

The use of models in educational planning has been limited not only by the orientation of individual planners toward the future but also by the models used. A review of the literature by Johnstone (1974) on the capabilities of mathematical models in educational planning uncovered three generally recognized limitations. The first dealt with how well models can predict the future. Mathematical models "cannot account for contingencies which arise unexpectedly or which are out of character with past events" (p. 132). Models, therefore, will only be able to predict approximately the most likely future. Secondly, mathematical models which integrate mathematical tractability and a realistic system representation were seen as impossible to develop. Johnstone explained.

> Models at a high level of tractability (e.g. simple linear equations) are adequate in the study of certain physical phenomena, but their ability to describe behaviour in the social sciences is severely limited through the almost complete absence of similar linear relationships between variables in this field.

> If however, a realistic representation is only possible through extremely complex mathematics, the model is not easily managed or manipulated, and thus concise description is impossible. The model becomes more difficult to manipulate than the situation itself. (p. 192)

The third limitation mentioned was that models rarely account for all the aspects of the planning process and therefore must be regarded as just one of the planning tools available (pp. 192-193).

The last limitation found by Johnstone centered on the need for integration of mathematical models with the total planning process and to broaden the scope of models. Fincher (1972) summarized a survey and study by Casasco (1970a, 1970b) in which the majority of models in education suffered from a lack of comprehensiveness and understanding by planners:

> Casasco views the main problem as the limited scope of present models within the total planning needs of colleges and universities. Only 29 percent of the models described in his survey were found to have a sufficient degree of comprehensiveness, a fact that Casasco attributes to the failure of administrators to view institutional development within the framework of a total systems plan. Elsewhere, he has written that this has led to a preoccupation with sophisticated analytical tools that are becoming the ends of planning rather than the means. Dealing only with operational problems such as space requirements, student enrollments, and institutional budgets, these planning tools have not only been underutilized but have led to misunderstandings of their possibilities and limitations. (Fincher, 1972, p. 782)

Schematically, Heigham (1969, p. 302) has shown how OR mathematical programming models have been used for systemwide educational planning, Figure 3. Models of the external

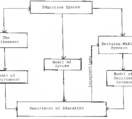

Figure 3. Use of OR Models in Central Planning

environment, the educational system, and the decision-making process were shown to be interrelated and integrated before effective planning was realized.

Criteria for the ideal planning process were identified by Ackoff (1970) as including five parts. They are:

> 1. Ends: specification of objectives and goals.
> 2. Means: selection of policies, programs, procedures, and practices by which objectives and goals are to be pursued.
> 3. Resources: determination of the types and amounts of resources required, how they are to be generated or acquired, and how they are to be allocated to activities.
> 4. Implementation: design of decision-making procedures and a way of organizing them so that the plan can be carried out.
> 5. Control: design of a procedure for anticipating or detecting errors in, or failures of, the plan and for preventing or correcting them on a continuing basis. (p. 6)

A mathematical programming model that optimizes resource allocations is regarded, therefore, as being just one part of the total planning process. McNamara (1971) stated that

> it should be emphasized that mathematical programming models do not make decisions, nor can they replace judgment on the part of the decision-maker. These models are designed to aid and support decision-makers by providing pertinent data on alternative programs and courses of actions. Planning models allow decision makers to form expectations being based on known empirical relationships and the decision-makers' own judgments. (p. 441)

One major difficulty recognized as contributing to the development of OR mathematical models in education and their integration into the total planning process has been the lack of effective communication between the model builder and the decision-maker. Indeed,

> contributing to this state of affairs is the obvious failure to realize that quantitative, computer-formed rationality is only one of the rationalities appropriate to a complex administrative problem. Political rationality, economic rationality, the valuing process or human relations concerns may be equally appropriate 'rational' approaches to the same problem. Since the value of solutions depends on how adequately the model represents the real world problem, effective communications between the consultant and his client are essential and must precede the model building activities. (McNamara, 1973, p. 29)

The determination of how adequate a particular model is for a particular planning objective within the comprehensive planning process had been of vital concern to educators. McNamara (1971) proposed the following group of questions that should be addressed to analyze educational planning models:

> What is the single system to be modeled? Should a unique model be built for each subsystem?
>
> Who are the decision-makers? What assumptions are made about the decision-maker who would use the model?
>
> Who is responsible for the generation of alternatives? How are they developed and by what criteria are they compared?
>
> What are the goals, overall objectives or targets involved? How are these concepts defined and how are they measured?
>
> What is the pertinent time span for the construction of the model as well as for its implementation once it can be validated?
>
> What supportive information systems are required for the model?
>
> What are the controllable variables? (For which decision-makers?)
>
> What are the uncontrollable variables? (For which decision-makers?)
>
> Can multiple criteria be translated to a single feature of merit? Does the concept of optimization vanish without a single criterion?

> How would you implement the model in its intended environment? Are costs of translating an ideal model to a workable model in the real world 'prohibitive'?
> How would you teach people to do the things that the model asks people to do? (pp. 8-9)

In sum, mathematical programming models in educational planning have been misunderstood, misused, abused, ignored, or oversold. Hard to quantify issues have been avoided. Personal leanings have been incorporated into models as a means to recruit model results for support. Models have not been effectively integrated into the total planning process. They have lacked a sufficient degree of comprehensiveness on the one hand, or have been so encompassing they have been rendered useless on the other.

If the potential of mathematical programming models was to be realized in the 1980's, increased emphasis had to be placed on achieving the following five objectives.

1. A closer communion between the technical model builder and the operative and policy making model users,

2. An increasing integration and interaction between large-scale models as conceptual "master plans" and smaller scale problem solving models dealing with immediate policy issues,

3. A deepening interface of modeling needs with the more routine transactional and stewardship reporting systems of institutional data base operations;

4. A growing emphasis on measuring and recording the outputs, outcomes, products, and effects of the educational experience on individuals and society, and

5. Continuing experimentation especially with various approaches to modeling logic, such

> as optimized heuristic, normative, and interactive systems in which more emphasis is placed on the order of-magnitude value judgments of the participants. (Mason, 1976, p. 106)

Linear Programming and the MPSX Computer Code

Introduction

The OR technique used to develop the mathematical model in the study was linear programming. The first portion of this section, therefore, is structured as follows First, the primary characteristics of linear programs were delimited. The basic mathematical nature of the technique was reviewed along with the necessary theoretical assumptions of linear programming. Next, the techniques of post optimality analysis were discussed. Finally, the utilization of post optimality analysis as a method of generating alternative system futures for use in long-range planning was presented.

In the final portion, the general development of linear programming computer codes is reviewed. Since the MPSX code was used in the study, its description comprised the major part of the discussion.

Linear Programming

Linear programming has been referred to as basically a mathematical tool for obtaining optimum solutions that do not violate various constraints, that cannot have negative activities, that require linearly proportional relationships, and that account for all inputs and outputs within the system

(Greenberg, 1978, p. 5). Figure 4 presents the general nature of a linear programming model.

A typical linear programming model is presented in vector notation as follows.

$$\text{Maximize } Z = cx, \qquad (2.1)$$

subject to

$$Ax \le b, \qquad (2.2)$$

and

$$x \ge 0, \qquad (2.3)$$

where c is the row vector

$$c = (c_1, c_2, \ldots, c_n),$$

x, b, and 0 are the column vectors such that

$$x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}, \qquad b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}, \qquad 0 = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix},$$

and A is the matrix

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{m1} & a_{m2} & & a_{mn} \end{bmatrix}$$

Equation 2-1 is called the objective function. It represents the function that is being maximized. Restrictions on the solutions to the objective function are described by equation 2.2. The restrictions are referred to as functional constraints. Equation 2-3 also represents a set of restrictions referred to as nonnegativity constraints. The x_j variables represent decision variables, while the c_j, b_i, a_{ij} are called model parameters (Hillier & Lieberman, 1974, p. 21).

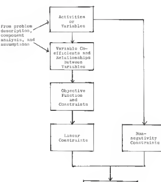
From problem description, component analysis, and assumptions
Activities or Variables
Variable Coefficients and Relationships Between Variables
Objective Function and Constraints
Linear Constraints
Non-negativity Constraints
Linear Program

Figure 4 A Linear Program (Adapted from Saikin & Saha, 1975, p. 3)

The central mathematical problem of linear optimization is to find a vector x which satisfies equations 2.1 through 2.3. In other words, linear programming is a process of selecting the values of the decision variables within a feasible region described by the model constraints which will yield the optimal value of the objective function (McNamara, 1971, p. 423).

The main characteristics common to all linear programming models were summarized by Daellenbach and Bell (1970). They identified the following common elements.

1. There exists an objective that is to be optimized, such as maximization of profits or minimization of costs.
2. There exist alternative courses of action, or decision variables, as we call them to achieve the desired objective.
3. There exist restrictions on the amount or extent of attaining the objective, that are expressed in the form of constraints on the values of the decision variables. (p. 5)

Implicit in the linear programming model formulation given by equations 2.1, 2.2, and 2.3 are the four model assumptions of proportionality, divisibility, additivity, and determinism. How well a particular problem can be put into the general model form outlined by the previously mentioned equations and also satisfy all four assumptions becomes a measure of the appropriateness for using a linear programming model. The assumptions of linear programming were highlighted by Hillier and Lieberman (1974):

> **Proportionality** In this case (1) the measure of effectiveness Z equals $c_k x_k$, and (2) the usage of each resource i equals $a_{ik} x_k$, that is, both quantities are directly proportional to the level of each activity k conducted by itself (k = 1,2,...,n)..
>
> **Divisibility.** The divisibility assumption is that activity units can be divided into any fractional levels, so that noninteger values for the decision variables are permissible..
>
> **Additivity.** The additivity assumption requires that, given any activity levels $(x_1, x_2, \ldots, x_n)$, the total usage of each resource and the resulting total measure of effectiveness equal the sum of the corresponding quantities generated by each activity conducted by itself ..
>
> **Deterministic.** The deterministic assumption is that all the parameters of the model (the a_{ij}, b_j, and c_j values) are known constants. In real problems this assumption is seldom satisfied precisely. Linear programming models usually are formulated in order to select some future course of action. Therefore the parameters used would be based on a prediction of future conditions. (pp. 22-24)

In certain cases, where some but not all of the assumptions of linear programming have been met, constructing a linear programming model of the problem has still yielded valuable results. Daellenbach and Bell (1970) mentioned that

> even if some of the conditions [linear programming assumptions] cited are not satisfied by a particular problem we may still attempt to use an LP model as a first approximation. If some components of the problem exhibit some random behavior, we may substitute averages for these components. If in practice the decision variables are restricted to integers only, it might be possible to approximate them by continuous variables and suitably round the solution obtained to integers. If the objective or some of the constraints exhibit in fact nonlinear behavior, we might attempt to substitute suitable linear approximations for them. (pp 5-6)

The algorithm used to solve linear programming models was developed by Dantzig in 1947 (Hadley, 1964, p. 14) and is referred to as the simplex method (see Dantzig, 1948, 1949). The simplex method is an iterative procedure that reaches an optimal solution to the model in a finite number of steps or gives an indication that the model solution is unbounded. Unbounded solutions arise in models where the objective function value Z can be made infinitely large. This situation generally indicates a misformulation of the model. A model that has an optimal solution must have an objective function value Z which is finite. The following two theorems summarize the discussion.

1. If a linear programming model has an optimal solution, at least one basic feasible solution will be optimal. (A basic solution is defined as a solution that has no more than m variables different from zero. Where m is the number of functional constraints. A basic feasible solution is defined as a basic solution where all m variables are non-negative and called degenerate if any of the m variables equals zero.)

2. If a linear programming model has a basic feasible solution which is not optimal, it is possible to obtain an optimal basic solution in a finite number of steps by changing a single basic variable at each step, or to obtain an indication of an unbounded solution. (Hadley, 1964, p. 31)

Proof of the two theorems and ultimately the use of the simplex method to solve a linear programming model is mathematically more convenient if the model has been converted from the form represented by equations 2.1, 2.2, and 2.3 to the following standard form:

$$\text{Maximize } Z = cx, \tag{2.4}$$

$$\text{subject to} \quad Ax = b, \tag{2.5}$$

$$\text{and} \quad x \geq o, \tag{2.6}$$

where in general the A, b, c, and x matrices are different here than those used in equations 2.1, 2.2, and 2.3. Transforming the inequality form of equation 2.2 to the equality form of equation 2.5 is accomplished by introducing additional variables called slack variables in the case of "less than" inequalities and surplus variables in the case of "greater than" inequalities. In addition, it is usually convenient if all components of the b vector are positive. Artificial variables must be added in some cases to secure an initial basic feasible solution.

Briefly, the simplex method begins with an initial basic feasible solution of the linear programming model in the standard form. It then computes the c_j's for all x_j's not in the basis. If all these x_j's have negative c_j's the simplex method concludes that the solution is optimal. If any x_j not in the basis has a positive c_j, the simplex first checks for the possibility of an unbounded solution. If there is no indication of an unbounded solution, the simplex method selects the x_j not in the basis with the largest positive c_j to enter the basis. The simplex method next removes an x_j in the basis in a manner to insure a new basic feasible solution. The procedure is repeated until an optimal solution or unbounded solution is reached.

To summarize the discussion on linear programming to this point, it was stated that a number of assumptions must be satisfied before linear programming can be considered as the appropriate technique for approaching a particular problem. Next, the steps of the simplex method were discussed. Naylor and Bryne (1963) summarized the procedure as follows.

> 1. Define the problem in terms of a linear objective function subject to a set of linear restraints.
> 2. Introduce slack and artificial variables to convert inequalities to equalities and provide a basic feasible solution to the problem.
> 3. Construct the initial simplex table for a basic feasible solution.
> 4. Determine which variable should be introduced into the solution, if the solution is not optimum.
> 5. Determine which variable should be removed from the solution.
> 6. Construct a new simplex table reflecting the changes that have been made in the solution.
> 7. Repeat steps 4 through 6 until an optimum solution is reached, i.e., until the solution cannot be further improved. (pp. 47-48)

In fact, the first two phases of the OR process as suggested by Ackoff (1956) and previously mentioned in the chapter have been addressed thus far. That is, the formulation of the problem and the construction of the linear programming model. The third phase of the OR process is to derive a solution from the model. The simplex method for obtaining linear programming model solutions was presented. In addition, procedures to determine the stability of the solution are necessary before the third phase is complete. The procedures have been called sensitivity analysis and have been grouped under a broader process variously referred to as post optimality analysis (Randolph & Meeks, 1978, p. 198), post optimization (Simonnard, 1966, p. 138), or postoptimal analysis (Greenberg, 1978, p. 118).

Sensitivity analysis has been referred to as the process for investigating the effect on the optimal solution of a linear programming model to changes in the model parameters—the a_{ij}'s, b_i's, and c_j's. Sensitivity analysis is important for several reasons. First, in some instances a few of the a_{ij}, b_i, and c_j parameters may be controllable (Dantzig, 1963, pp. 266-267). The effects of changes in these parameter values would be desirable to know since, for example, advantages may be gained in the objective function value. Model parameters, particularly the b_i's, are sometimes "set as a result of policy decisions . . . and these decisions should be reviewed after seeing their consequences on what can be achieved" (Hillier & Lieberman, 1974, p. 182).

Another reason for sensitivity analysis arises from the fact that the a_{ij}, b_i, and c_j values may only be estimates based on some approximation of conditions in the future. The deterministic assumption of linear programming models stated that the a_{ij}, b_i, and c_j be known constants, but in reality this assumption can rarely be said to hold. Sensitivity analysis is used to determine the stability of the optimum solution when the model parameters are assumed constant and the actual values of these parameters are only approximations. If the optimum solution changes with small changes in any of the parameters the relationship between the sensitive parameters and the solution must be critically analyzed. On the other hand, an optimum solution that is insensitive to small parameter changes indicates a reliable linear programming model solution (Greenberg, 1978, p. 57).

A third reason for sensitivity analysis relates also to the assumption that the a_{ij}, b_i, and c_j parameters are known constants. In this case the parameters are known but recognized as variable. Sensitivity analysis gives the range any parameter or set of parameters can vary within while the current solution remains optimal (Dantzig, 1963, p. 267).

The importance of the discussion on sensitivity analysis relates directly to how the linear programming model developed in the study was used for long-range planning by generating multiple system futures and developing system strategies to adapt, prevent, or achieve each possible future. When, for example, sensitivity analysis is used to define the range of a model parameter (a_{ij}, b_i, and c_j) where the model solution remains optimal, it becomes a measure of the optimal solution evaluation criterion called resilience. Nair and Sarin (1979) explained that

> resilience can be defined as the ability of a plan [optimal solution] to perform adequately under a variety of futures. Resilience can be measured in a number of ways. The cost to change plans might be one measure. The variation from some desired performance under various future scenarios might be another measure. Therefore, an essential element

> of the evaluation process is the development of future scenarios under which plans [optimal solutions] should be evaluated. (p. 57)

A technique frequently used by United States industrial companies to evaluate proposed strategies when subject to alternative futures has been multiple (or alternative) scenario analysis (MSA) (Linneman & Klein, 1979, p. 83). The following steps describe the general MSA procedure.

> (a) isolating assumptions about the future which you are sure will occur within your planning timeframe, (b) identifying key 'impact variables', (c) specifying other environmental variables which might affect the behavior of the impact variables--what might be called 'cross impacts', (d) constructing at least two descriptions of possible future--scenarios--which depict a range of behavior of the impact variables, and (e) developing strategies which are responsive to one or more of the scenarios. (Linneman & Klein, 1979, p. 83)

How resilience and MSA relate to linear programming sensitivity analysis is obvious. Yet two critical points must be resolved during the early period of any scenario exercise. First a time scale or planning horizon must be determined and secondly the number of scenarios which will be investigated must be set (Chapman, 1976, p. 4). Selection of the five-year planning horizon for the linear programming model developed in the study was based on a priori determination of the period. A number of quantitative approaches to determine planning horizons have been developed but were not amenable to the study model (Friedman & Segev, 1976, Modigliani & Hohn, 1955). The planning horizon was necessarily set on the basis of the accuracy and availability of various future forecasts incorporated into the model

The other crucial decision involves setting the number of scenarios to develop and explore. Results of a survey conducted by Linneman & Klein (1979) on the number of scenarios generated by a sample of corporations are presented in Table 2.

Table 2
Number of Scenarios Generated
(Adapted from Linneman & Klein, 1979, p. 87)

Number of Scenarios	Number of Companies
2	11
2-3	1
3	20
3-4	4
4	2
more than 6	1

More than half the respondents listed the number of scenarios typically generated for their most distant planning horizon as three. In the study model three scenarios were also used. The reasons for using three included the following: (1) keeping the scenarios developed down to a manageable number, (2) time and cost constraints limited exploring many more scenarios, and (3) it was assumed the three scenarios used represented futures with the highest probabilities of occurrence. The last point need not be an assumption of course. Methods such as cross-impact analysis (Fontela, 1977), the delphi technique (Linstone & Turoff, 1975), and bayesian statistics (Morris, 1974, 1977) do indeed provide procedures for ranking scenarios. Rigorous application of a model such as the one developed in this study would include utilizing such techniques.

In summary, the linear programming OR approach has been reviewed in general terms. The review of literature to this point has been developed after Naylor's (1977) six-step approach for integrating planning models into the planning process:

1. Review of the planning environment.
2. Specification of planning requirements.
3. Definition of goals and objectives for planning.
4. Evaluation of existing planning resources.
5. Design of an integrated planning and modeling system.
6. Formulation of a strategy for integrating the planning model into the planning process. (p. 11)

In addition to addressing the question of integrating the model into the overall planning process, the first five of the following eight basic elements Naylor and Mansfield (1977) considered essential for specifically designing computer based planning and modeling systems have been investigated:

1. Planning System.
2. Management Information System.
3. Modeling System.
4. Forecasting System.
5. Econometric Modeling.

6. User Orientation of the System.
7. System Availability.
8. Software System. (p. 16)

The last three elements are attended to in the final section of the literature review on the MPSX computer code.

MPSX Computer Code

The first linear programming model solved using a digital computer was on the National Bureau of Standards computer, the SEAC, in 1952 (Gass, 1975, p. 235). In the early 1950's, models with as many as two hundred functional constraints and a thousand decision variables were accomodated and solved in approximately five hours by computers (Dantzig, 1963, p. 26). By 1975, successful solutions had been obtained for linear programming models with 50,000 functional constraints and 265,000 decision variables (Salkin & Saha, 1975, p. 40).

Two approaches have been used to derive solutions from complex linear programming planning models on computers. The first has been to use scientific programming languages such as FORTRAN or APL. Another approach taken has been to use already existing planning and modelling software systems, or computer codes.

Advantages of developing specific computer programs for every linear programming model have included the extreme flexibility of scientific programming languages and also the fact that the languages have been well-known. Disadvantages have included the following:

1. The possibility planners are not familiar with any of the languages.
2. The main application strengths of languages such as FORTRAN and APL do not include data-based management and report generation.
3. The languages cannot provide assistance in formulating and coding models.
4. Changes in policy assumptions, report formats, external assumptions, and forecasts cannot be implemented easily (Naylor & Mansfield, 1977, pp. 23-24).

Disadvantages of using already existing planning and modeling softward systems have included the fees users must pay to the leading firm and the fact that the computer running costs are higher. The advantages of using planning and modeling software systems that have been designed to assist the planner formulate and code models have included the following:

1. The systems are easy to use.
2. The systems provide a conceptual framework for planning and modelling making model development easier.
3. They are reasonably flexible.
4. Implementing such things as forecasting are much easier.
5. Use of already existing systems usually lead to reduced total project costs (Naylor & Mansfield, 1977, pp. 23-24).

In the study, an existing planning and modelling software system was used primarily to make model parameter changes, which represented multiple scenarios, easier. Additionally, using a software system represented a considerable savings in time and total study costs.

In 1980, there existed many commercially available linear programming software systems, or computer codes. Salkin & Saha (1975, pp. 40-46) listed and described twelve such codes that have been frequently used. International Business Machines' (IBM) Mathematical Programming System Extended (MPSX) computer code was used in this study. Standardization and availability were the main reasons for choosing the MPSX code.

The general MPSX card deck layout is presented in Figure 5. Cards 1-6 are the job control language cards (JCL) which provide control information to the computer system. The JCL depicted were for the University of Florida. The control program and data vary for each model. A number of publications have listed the formatting requirements and available MPSX options (see Greenberg, 1978, pp. 99-127, Randolph & Meeks, 1978, pp. 41-231, Sposito, 1975, pp. 241-260).

Summary

The review of the literature demonstrated that the operations research technique of linear programming applied to macro educational planning is an appropriate approach to long-range planning, particularly in view of the advances made in statewide postsecondary education coordination. Additionally, linear programming and the MPSX computer code were shown to facilitate multiple scenario analysis. Subsequent

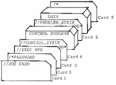

Figure 5 MPSX Card Deck Layout

chapters attempt to develop a general linear programming model for statewide postsecondary education systems and demonstrate the use of the model to devise long-range system strategies that adapt to, prevent, or achieve various system futures.

CHAPTER III
MODEL DEVELOPMENT

Introduction

The focus in this chapter is on the development of a prototype linear programming model for postsecondary education systems in the United States. The multiple scenario analysis approach is used to create different system constraint conditions. The model is employed, then, to devise alternative system strategies that consider each new scenario situation.

The major aspects of the model are comprised of three submodels. Simply stated, the first submodel is the student vector or supply aspect of the model. The number of students in a particular program at a particular postsecondary education institution was controllable by constraint equations which incorporated variables such as the potential student pool, funding patterns, and square feet of assignable space. The second submodel is the future occupational demand aspect of the model. This future demand was described in terms of manpower requirements as a function of state geographic area and occupation. The last submodel integrated the flow of postsecondary education institution program graduates into "initially entered" occupations. The integration relation was represented by a probability matrix of where graduates of particular programs from particular postsecondary education institutions go in the state and what occupations they initially enter.

The model has incorporated highly aggregated aspects of student flow modeling, fiscal planning, program planning, facilities planning, and manpower requirements modeling. In this chapter, factors that were used to construct linear constraint equations in each of the three submodels are described.

Forecasting the Supply of Graduates Submodel

Numerous enrollment projection techniques have been developed that vary considerably in sophistication and applicability. Various descriptions of enrollment projection techniques have been made by Lins (1960), Lyell and Toole (1974), and Mangelson, Norris, Poulton, and Seeley (1974). The most frequently used mathematical enrollment projection techniques have been trend analysis, curve fitting techniques, ratio method, cohort survival, regression analysis, and Markov chains. Render (1977) combined several of the techniques in a state system enrollment forecasting model (pp 21-26). Indeed, as Render stated,

> the techniques listed above may not be considered mutually exclusive, for all could conceivably be present in a given study of national or statewide forecasting. (p. 21)

Since a number of techniques have been developed and the possibility of using more than one technique in a comprehensive model of statewide enrollment projections has been recognized, the problem has been reduced to choosing the technique or combination of techniques best suited to the purposes and orientation of the planning. Evans (1975) cautioned, however, that

> the constraints inherent in the methods cited above are abundant, and the detriment incurred in their use (particularly the less sophisticated cohort, ratio, and curve-fitting approaches) varies with the context of the application. (p. 1)

The classification system for categorizing enrollment projection techniques described by Gardner (1980) was used to integrate the overall planning objectives of the linear programming model with the supply relations. Gardner described four basic types of enrollment forecasting methods:

> 1. Patterned based. Methods in this category attempt to identify an underlying pattern in the historical data, describe it in mathematical terms, and then extrapolate it into the future. . . .
>
> 2. Correlation analysis. This type of approach develops projections on the basis of the numerical values of "leading indicator" variables which have been demonstrated, e.g., through the use of multiple regression, to have a strong relationship to enrollment levels. . . .
>
> 3. Intention surveys. Intention surveys involve sampling specific groups to determine college attendance plans. . . .
>
> 4. Professional judgment. . . . The lack of objectivity of this method may be more than offset by the benefit of experienced judgment and interpretation of subtle factors influencing enrollment not easily captured by mathematical models. (pp. 2-3)

Patterned based techniques, correlation analyses, intention surveys, and the professional judgment technique have all been integrated in the construction of the supply segment of the model. The procedure to calculate the supply of postsecondary education institution program graduates was divided into three steps: (1) the highly probable student demand calculation, (2) formulation of the student access control equation, and (3) the calculation of the number of graduates.

Step 1 -- Determining the Probable Student Demand

A description of what the probable student demand calculation is might best be accomplished by an examination of what it is not. It is not the number of students that will be attending public postsecondary education institutions at some specified time in the future. It is not a highly abstract enigma, nor an information-hungry simulation model.

The calculation is a first approximation of what might result in the future with program enrollments derived from straightforward patterned based techniques. Both causal and trend dimensions were integrated using the ratio method and the double exponential smoothing technique in a linear combination that could be tempered with professional judgment by the selection of weighting factor values. The particular form of the calculation is as follows.

$$H_i = \frac{\lambda_i}{\lambda_i + \delta_i} R_i + \frac{\delta_i}{\lambda_i + \delta_i} \hat{X}_i, \qquad (3.1)$$

where time subscripts are understood and

H_i is the probable student demand by program headcount for institution i for future time t,

R_i is the program headcount enrollment forecast for institution i by the ratio method for future time t,

$\hat{X}_i$ is the program headcount enrollment forecast for institution i by the double exponential smoothing technique for future time t,

λ_i is the weighting factor for the ratio method forecast of program headcount enrollment for institution i for future time t, and

δ_i is the weighting factor for the double exponential smoothing forecast of program headcount enrollment for institution i for future time t.

The calculation of the program headcount enrollment forecast for institution i by the ratio method (R_i) is straightforward. Briefly, a simple table in the form of Table 3 is employed to organize data. Data on program headcount by institution, age cohort, and county as well as total population by age cohort and county are compiled over a base period of x years from a year s through year (s + x-1). Here, (s + x-1) represents the most recent year that data were available for and is defined as the base year. For each year y in the base period, the ratio $d_{\ell y}$ of the program headcount enrollment to total population by age cohort ℓ is calculated. Next, all the $d_{\ell y}$ ratios for the entire base period in a particular age cohort are considered to obtain an adjusted ratio d'_{ℓ}. A degree of professional judgment is interjected at this point to decide whether or not to use the median of the $d_{\ell y}$ ratios, the mean, the most recent value, or the trend pattern. The adjusted ratios are multiplied by the age cohort population forecast for future year t to yield enrollment forecasts by age cohort and county. By summing these forecasts over all counties and age cohorts the program headcount enrollment forecast for one institution is obtained. For example, if the $d_{\ell y}$ ratios are combined to obtain adjusted ratios by taking their mean, the program headcount enrollment forecast for institution i by the ratio method for future time t becomes

$$R_i = \frac{\sum_k \sum_\ell e_{\ell kt}}{x} \sum_{y=1}^{x} \left[\frac{\left(\sum_k a_{\ell ky} \right)^2}{\left[\sum_k c_{\ell ky} \right] \left[\sum_k \sum_\ell a_{\ell ky} \right]} \right], \qquad (3.2)$$

where

R_i is the program headcount enrollment forecast for institution i by the ratio method for future time t,

$e_{\ell kt}$ is the population forecast by age cohort ℓ and county k for future time t,

$a_{\ell ky}$ is the program headcount enrollment for institution i by age cohort ℓ and county k for base period year y,

$c_{\ell ky}$ is the population by age cohort ℓ and county k for base period year y,

x is the number of years in the base period, and

y is a base period year, where y = 1,2,3,. . .,x.

A further description of the ratio method as well as a listing of suggested population data sources have been provided by Lins (1960, pp. 11-15).

Table 3
Calculation of the Program Headcount Enrollment Forecast for One Institution by the Ratio Method

	A Enrolled in Programs County (k) 1,2,...,n	B % of Total	C Total Population County (k) 1,2,...,n	D Ratio	Repeat A,B,C, and D for each year *y* in the base period. Here, y-1,2, ...,x
Age Cohort ℓ	$a_{\ell ky}$	$b_{\ell y}=\frac{100\sum_k a_{\ell ky}}{\sum_k\sum_\ell a_{\ell ky}}$	$c_{\ell ky}$	$d_{\ell y}=\frac{b_{\ell y}\sum_k a_{\ell ky}}{100\sum_k c_{\ell ky}}$	

	D' Adjusted Ratio	E Total Population for Future Year t County (k) 1,2,...,n	F Enrollment Forecast for Future Year t County (k) 1,2,...,n
Age Cohort ℓ	d'_ℓ	$e_{\ell kt}$	$f_{\ell kt}=d'_\ell e_{\ell kt}$

Ratio Method Forecast for Institution i
$R_i = \sum_k \sum_\ell f_{\ell kt}$

The ratio method is a patterned based enrollment forecasting technique that is causal in the sense that the forecast it yields is a function of the anticipated state population by age cohort. For postsecondary education institutions such as community colleges that have had a student market comprised of primarily in-state students, the ratio method as described has worked accurately. For an institution that draws heavily from out-of-state, however, a modification to R_1 is required where the median, mean, the most recent, or the trend determined value of the out-of-state headcount enrollment for future time t is added to R_1.

The overall linear trend in total program headcount enrollment is introduced into the probable student demand calculation by the second term in equation 3.1. The second term, $\hat{X}_i$, is the double exponential smoothing forecast of program headcount enrollment for institution i for future time t. Wheelwright and Makridakis (1973, pp. 44-47) have provided a detailed analysis of the theoretical foundation of the technique. The basic mathematical calculation is summarized as follows

$$\hat{X}_i = 2 + \left[\frac{\alpha(t-s-x+1)}{\alpha-1}\right] S'_{x+1} - \left[1 + \frac{\alpha(t-s-x+1)}{\alpha-1}\right] S'_{x+1} , \quad (3.3)$$

with

$$S'_{y+1} = \alpha X_y + (1-\alpha)S'_y \; , \qquad (3.4)$$

$$S_{y+1} = \alpha S'_{y+1} + (1-\alpha)S'_y \; , \qquad (3.5)$$

where

X_i	is the third level double exponential smoothing program enrollment headcount forecast for institution i for future time t,
S'_{y+1}	is the single exponential smoothing forecast for base period year y+1,
S'_{y+1}	is the second level double exponential smoothing term for base period year y+1,
(t-s-x+1)	is the number of years into the future that the forecast is made from the base year,
α	is the exponential smoothing constant with a value from 0 through 1,
X_y	is the actual program enrollment headcount for base period year y at school i,
x	is the number of years in the base period, and
y	is a base period year where $y = 1,2,3,\ldots,x$.

The procedure for determining $\hat{X}_i$ is to first compute S'_{y+1} and S'_{y+1} for the first year in the base period, $y = 1$, and then repeat these calculations for the remainder of the base period years through $y = x$. Once S'_{x+1} and S'_{x+1} have been obtained, simply substituting their values in equation 3.3 yields the double exponential smoothing forecast of program headcount enrollment for institution i for future year t.

Of critical importance when using the double exponential smoothing technique is the value of α used in the calculation. The larger the value of α, the greater the weight is given to the more recent values of X_y to determine the enrollment trend projected into the future. The selection of α is facilitated by the use of the Average Absolute Differences' method (Gardner, 1980, pp. 10-11). Using the technique, different values of the exponential smoothing constant α are generated to compute different S'_{y+1} for each year y in the base period. For each value of α the absolute differences over the entire base period between S'_{y+1} and the actual program headcount enrollment value X_{y+1} for each base year y are calculated. The α chosen to estimate future program headcount enrollments will be the α which has yielded the smallest average absolute error value. Expressed mathematically,

$$E(\alpha_z) = \frac{1}{x} \sum_{y=1}^{x} \left| S'_{y+1}(\alpha_z) - X_{y+1} \right| , \qquad (3.6)$$

where

$E(\alpha_z)$ is the average absolute error value with $\alpha = \alpha_z$ where $z = 1,2,3,\ldots,m$,

S'_{y+1} is the second level double exponential smoothing term for base period year y+1,

X_{y+1} is the actual program headcount enrollment at school i for base period year y+1,

x is the number of years in the base period,

y is the base period year where $y = 1,2,3,\ldots,x$, and

α is the exponential smoothing constant with a value from 0 through 1.

Table 4 summarizes the double exponential smoothing calculations.

Table 4
Calculation of the Program Headcount Enrollment
Forecast for One Institution by the
Double Exponential Smoothing Technique

Academic Year	Base Period Year	Actual Enrollment Headcount	$\alpha = \alpha_1$		etc.	$\alpha = \alpha_m$	
			Single Smoothing	Second Level Smoothing		Single Smoothing	Second Level Smoothing
s	1	X_1					
s + 1	2	X_2					
s + 2	3	X_3	S'_3	S''_3		S'_3	S''_3
.	.	.					
.	.	.	.			.	
.	.	.	.			.	
s+x-1	x	X_x	S'_x	S'_x		S'_x	S'_x
		Average Absolute Error	$E(\alpha_1)$			$E(\alpha_m)$	

Academic Year	Base Period Year	Use α from $\min[E(\alpha_z)]$	
		Single Smoothing	Second Level Smoothing
s + x	x + 1	S'_{x+1}	S_{x+1}

Double Exponential Smoothing Forecast For Institution i	X_i

Once the ratio method and double exponential smoothing program headcount enrollment forecasts have been computed for an institution for future time t the values are inserted in equation 3.1. To complete the program headcount probable student demand calculation, H_i, only the values of the weighting factors λ_i and δ_i are required. As mentioned earlier in this section, the weighting factor values are determined by professional judgment. Indeed, the forecasts obtained by the ratio method and the double exponential smoothing technique in reality set bounds on the probable student demand. The weighting factors allow the knowledgeable administrator to prejudice H_i more toward one of the forecasts than the other.

Since individual institutions and entire state postsecondary education systems have allocated resources and reported statistics on operations with the full-time equivalent (FTE) student and not the headcount student as the common denominator, the student demand calculation, H_i, is converted in the final step from a program headcount figure to a FTE student figure by the FTE to headcount ratio for the institution. This ratio is determined also by the double exponential smoothing technique previously described. To summarize,

$$F_i = g_i H_i \ , \qquad (3.7)$$

where

F_i is the probable student demand in program FTE's for institution i for future time t,

H_i is the probable student demand calculation by program headcount for institution i for future time t, and [illegible] is the third level double exponential smoothing ratio of program FTE's to head-count for institution i for future time t.

Step 2 -- Controlling Student Access

Equation 3.7 was derived to estimate the student demand in program FTE's for an institution at some future time t assuming that current trends are projected linearly into the future. In calculating F_i it was assumed, for example, that the general characteristics of the student market for school i, the number of square feet of assignable space, the admission policy, scheduling patterns, and the funding, tuition, and aid trends all remain stable over the base year through future year t time period. Calculation of F_i was accomplished using an exploratory futures forecasting approach. One will recall from the first chapter that exploratory methods simply extend past or current patterns into the future. Yet the variables inherent in calculating F_i assumed to be linear projections of past trends are not inflexible, mandated entities but to a large degree reflect controllable administrative policies at the state and/or institutional level. In the first chapter, normative futures forecasting techniques were defined as beginning first by determining future needs or goals at time t and then formulating a strategy to attain the goals working forward from the base year. Any policy change different from the trend projection of that policy into the future therefore constitutes an alternative probable student demand future from the one depicted by equation 3.7.

For purposes of discussion and analysis, only two policy dimensions were considered in the model. Ideally, the effect of altering policies from their trend projections on equation 3.7 would include investigating funding patterns, square feet of assignable space, admissions policy, tuition, and student aid dimensions. Only cost and square feet of assignable space for institutions by programs were included in the model. With just two dimensions available to create alternative strategies that adapt to, prevent, or achieve various future scenario conditions, a considerable number of possibilities exist. Demonstrating this point is the subject of the next chapter.

The first constraint limits the number of full-time equivalent (FTE) students enrolled in programs at a particular institution to being less than or equal to the probable student demand calculation, F_i, for the institution. By not changing admission policies, tuition, and student aid trends, F_i can be interpreted as setting an upper bound on the number of FTE's that will be generated by an institution at some future point in time. The degree to which the F_i's are satisfied for all postsecondary education institutions therefore indicates how well the system meets the anticipated needs of the citizenry. In sum,

$$\sum_j P_{ij} \leq F_i \,, \qquad (3.8)$$

where

P_{ij} is the number of FTE students enrolled at institution i in program j for future time t, and

P_i is the probable student demand calculation in program FTE's for institution i for future time t.

A program cost constraint limits the number of program FTE's at an institution in each program area at a future point in time. For each program at an institution

$$P_{ij}c_{ij} \leq C_{ij} , \qquad (3.9)$$

where

P_{ij} is the number of FTE students enrolled at institution i in program j for future time t,

c_{ij} is the cost per FTE student enrolled at institution i in program j in base year dollars, and

C_{ij} is the total dollar allocation in base year dollars for program j at institution i for future time t.

By equation 3.8, P_{ij} is a finite number. Equation 3.9 facilitates the control of (1) program FTE student distribution, (2) the extent that the probable student demand for educational services at an institution are satisfied, and (3) the manner in which institutional resources are distributed.

Extensions of equation 3.9 from resource allocation at the program level to resource allocation at the institutional and at the state level are described by equations 3.10 and 3.11,

$$\sum_j P_{ij}c_{ij} \leq \sum_j C_{ij} , \qquad (3.10)$$

$$\sum_i \sum_j P_{ij}c_{ij} \leq \sum_i \sum_j C_{ij} . \qquad (3.11)$$

Equation 3.10 expresses the statement that the total money allocated to all programs at an institution cannot exceed the money the institution has available. Equation 3.11 states that the total money spent by state postsecondary education institutions cannot exceed the amount allocated by the state legislature. The last constraint needs modification in the case where local tax support for postsecondary education institutions exists.

To summarize, the program cost constraint set of equations 3.9, 3.10, and 3.11 address the following three questions:

1. How much money should the state provide for postsecondary education?
2. How should the state funds provided for postsecondary education be distributed to postsecondary education institutions?
3. How should the funds provided to postsecondary education institutions be distributed to programs?

In similar fashion, the number of program FTE's at an institution is constrained by the physical facilities available for instruction. The facility constraints are

$$P_{ij}a_{ij} \leq A_{ij} \, , \qquad (3.12)$$

$$\sum_j P_{ij}a_{ij} \leq \sum_j A_{ij} \, , \qquad (3.13)$$

$$\sum_i \sum_j P_{ij}a_{ij} \leq \sum_i \sum_j A_{ij} \, , \qquad (3.14)$$

where

P_{ij} is the number of FTE students enrolled at institution i in program j for future time t,

a_{ij} is the number of assignable square feet of space required for instruction per FTE student enrolled in program j at institution i,

A_{ij} is the total number of assignable square feet of space for program j at institution i for future time t.

Both the program cost and facility constraints incorporate aspects of exploratory and normative futures forecasting techniques. For example, both c_{ij} and a_{ij} are determined by historical data utilizing exploratory methods. On the other hand, C_{ij} and A_{ij} are set a priori and represent the normative approach to futures forecasting. For each different C_{ij} and A_{ij} selected, an alternative postsecondary education system future state is achieved. Indeed, each C_{ij} and A_{ij} set chosen represents a specific postsecondary education system strategy to respond to a specific social demand-economic need future scenario. The social demand aspect of the scenario has already been delimited to the probable student demand calculation, F_i. The economic need aspect is represented by manpower requirements projections described in a later section of this chapter. Within the confines of total system fund and facility resources, the degree that a particular set of C_{ij} and A_{ij} values satisfy the social demand-economic need scenario is in fact a measure of the adequacy of the strategy.

Step 3 -- Estimating Graduates

The third and final step in the supply of graduates submodel is the calculation of the expected number of graduates from a particular program at an institution at some future point in time. Patterned based techniques are used to derive the ratio of the number of program graduates to the number of program FTE students for future time t which, when multiplied by the anticipated number of program FTE students for future time t, yields the anticipated number of program graduates for that year. Simply put,

$$G_{ij} = r_{ij}P_{ij} , \qquad (3.15)$$

where

G_{ij} is the number of anticipated graduates from program j at institution i for future time t,

r_{ij} is the ratio of the number of graduates from program j at institution i to the number of FTE students in program j at institution i for future time t, and

P_{ij} is the number of FTE students enrolled at institution i in program j for future time t.

Equation 3.15 expresses the assertion that given an empirically determined ratio of the number of graduates to the FTE enrollment in a program at a postsecondary education institution, the expected number of graduates from that program for some future year can be estimated if the FTE program enrollment is given. Conversion to headcount graduates is necessary since manpower requirements projections on the whole have estimated the number of individuals needed by various occupations. The integration of future occupation demand and student flow constraints is the topic of the next two submodels.

Forecasting Occupation Demand Submodel

The occupation demand segment of the model involves the generation of a forecast of the demand for manpower by occupation and state geographic region for some future time. Manpower requirements models, such as those developed by Chance (1966), Correa (1969a), Le Vasseur (1969), Maki (1970), and Ritzen (1976), have modeled relationships between the education and economic sectors to optimize investments in education in order to satisfy labor demands. Indeed, the forecasting of manpower needs has become a routine matter in various divisions of federal and state agencies. The increasing level of sophistication and mathematical rigor of the state-of-the-art manpower models advises the integration of existing manpower forecasts with this model and not the development of a manpower submodel to generate original forecasts. Thus, the problem reduces to one of locating and integrating existing manpower forecasting efforts.

A problem that has existed with the integration of federal manpower requirements forecasts into the model, for example the manpower forecasts available through a review of the *Dictionary of Federal Statistics for Local Areas* (U. S. Department of Commerce, 1978), has been that manpower requirements forecasts have been reported in statistics too highly aggregated by occupational group and by geographic region. Ideally, forecasts for occupations requiring post-secondary education training by state county are needed for the model.

A review of the Dictionary of Occupational Titles (U. S. Department of Labor, 1977) showed that the federal government has broken occupations up into nine broad categories. The nine categories have been further subdivided into a nine-digit DOT number which delimits a specific job title. The first three digits of the DOT occupational titles represented occupational groups that best related to preparation programs offered in postsecondary education institutions. In 1980, there were 979 three-digit occupational group DOT numbers specified. Manpower requirements forecasts existed for a number of the groups, however no unified, comprehensive analysis of all 979 occupational groups was found. The model is handicapped to the extent that manpower needs forecasts for occupations requiring postsecondary education training are available.

Manpower forecasts for highly delimited occupational groups by the federal government have used states as the local areas or regions for statistical reporting almost invariably. Breaking down the state totals for expected additional manpower by DOT number for some future time by county was accomplished by taking the arithmetic mean of two elements, one prorating the change in occupation need to the ratio of anticipated county population to anticipated state population change from the base year to the future year, the other prorating the manpower requirements using the ratio of future county to state population. To summarize,

$$\sum_k O_{k\ell} = \frac{\sum_{m=s+x-1}^{t} \left(\sum_k O_{k\ell m}\right)}{(t-s-x+1)} + \frac{\sum_k O_{k\ell(s+x-1)} + \sum_k O_{k\ell t}}{2} d_\ell \,, \tag{3.16}$$

$$O_{k\ell} = \frac{1}{2}\left[\frac{P_k' - P_k}{\sum_k (P_k' - P_k)} + \frac{P_k'}{\sum_k P_k'}\right]\left(\sum_k O_{k\ell}\right) \,, \tag{3.17}$$

where

$\sum_{m=s+x-1}^{t}\left(\sum_k O_{k\ell m}\right)$	is total additional manpower needs for occupation ℓ in a particular state from the base year $(s+x-1)$ through future time t,
$\sum_k O_{k\ell}$	is the total additional manpower needs for occupation ℓ in a particular state for future time t,
P_k'	is the anticipated population of county k for future time t,
P_k	is the population of county k in the base year,
$O_{k\ell}$	is the total additional manpower needs for occupation ℓ in county k for future time t, and
d_ℓ	is the attrition rate for occupation ℓ.

Once the overall additional manpower needs by occupation and county for some future time have been computed, in-migration and private institution shares must be considered before a figure can be obtained for the maximum number of program graduates that institutions in the public postsecondary education system should generate. Both factors can be obtained using patterned based forecasting techniques. Assuming that private institution graduates and in-migrating individuals distribute in a state in proportion to county population, the result is

$$J_{k\ell} = (O_{k\ell} a_{\ell}) - m_{\ell} , \qquad (3.18)$$

where

$J_{k\ell}$	is the anticipated need for public postsecondary education graduates for occupation ℓ in county k for future time t,
$O_{k\ell}$	is the total additional manpower needs for occupation ℓ in county k for future time t,
m_{ℓ}	is the average number of jobs per county in occupation ℓ filled by in-migrating workers for future time t, and
a_{ℓ}	is the fraction of jobs in occupation ℓ filled by public institution graduates for future time t.

The Student Flow Submodel

The last model segment integrates the product of postsecondary education institutions, namely graduates, with the future manpower needs of the state. The overriding interest in developing constraints in this submodel is that a postsecondary education system should be in tune with the economic needs for an educated work force of specific composition. Too few graduates prepared for a certain occupational group produces manpower shortages, decreased service quality, and economic loss. Too many graduates prepared for a certain occupational group produces manpower oversupplies, frustration, and results in wasted investment both by the state and the individual. Blame for either situation rests with ineffective educational planning. The very fact that both students and state funds earmarked for postsecondary education systems are scarce resources dictates that supply and demand factors be an integral part of responsible educational planning.

Accomplishing the goal of supply and demand integration is achieved by first ascertaining which occupations graduates of particular programs have entered in the past. These quantities are defined as participation rates. Assuming that the participation rates remain stable until the planning horizon, when the rates are equated with future occupation needs, they gauge how many and in what program areas graduates from particular postsecondary education institutions are required in specific areas of a state.

Participation rates are determined by an analysis of where and into what occupations the past graduates of particular programs at an institution have entered after some defined time lapse after graduation. The time lapse functions as a job hunting and adjustment period for graduates. Participation rates are necessary for relating each program an institution offers to each occupational group in each county in the state. Table 5 summarizes the information required where the $a_{jk}(i,\ell)$ are defined as the participation rates for graduates from program j at institution i that have found employment in occupation ℓ in county k.

Table 5
The Student Flow Matrix -
Participation Rates $a_{jk}(i,\ell)$

		County			
		$k = 1$	2	3	etc.
Institution	Program	Occupation $\ell=1\ 2\ldots$	Occupation $\ell=1\ 2\ldots$	Occupation $\ell=1\ 2\ldots$	.
$i = 1$	$j = 1$ 2 3	$a_{j1}(1,\ell)$	$a_{j2}(1,\ell)$	$a_{j3}(1,\ell)$	.
2	1 2 3 .	$a_{j1}(2,\ell)$	$a_{j2}(2,\ell)$	$a_{j3}(2,\ell)$	. . .
3	1 2 3 .	$a_{j1}(3,\ell)$	$a_{j2}(3,\ell)$	$a_{j3}(3,\ell)$	. . .
. .		.		.	. .

Once the participation ratios have been determined, constraint relations are formulated. Two constraints result and are summarized as follows.

$$\sum_{\ell} \sum_{k} a_{jk}(i,\ell) \leq 1 \ , \qquad (3.19)$$

$$\sum_{i} \sum_{j} G_{ij} a_{jk}(i,\ell) \leq J_{k\ell} \ , \qquad (3.20)$$

where

$a_{jk}(i,\ell)$ is the participation rate of graduates from program j at institution i in occupation ℓ in county k,

G_{ij} is the number of anticipated graduates from program j at institution i for future time t, and

$J_{k\ell}$ is the anticipated need for public postsecondary education graduates for occupation ℓ in county k for future time t.

Equation 3.19 expresses a conservation of graduates relation. The participation rates describe what fraction of graduates from a particular program at an institution find employment in a particular occupation and where that employment is. Equation 3.19 states that the sum of all participation rates for graduates from a particular program at an institution must be less than or equal to one. This allows for the fact that program graduates from postsecondary education institutions continue going to school, leave the state, or fail to find employment after the lapse period in any one of the 879 defined occupational groups.

Equation 3.20 is the manpower requirements constraint relation. Simply stated, it mathematically expresses the policy that the postsecondary education system will admit students in a particular program only to the point where there exists a reasonable probability of employment resulting from that program after program completion.

Since most postsecondary education institutions have not regularly conducted follow-up studies of graduates, obtaining existing data for the submodel constraint relations will be severely handicapped until the situation changes. Ideally, a simple questionnaire sent to a sample of graduates one year after graduation would enable the calculation of participation rates. Approximations of the participation rates could be derived from data already existing at institution alumni offices as a starting point.

The Objective Function

The objective function for the model reflects the philosophy that the goal of a state's postsecondary education system is to provide the best possible education to the greatest number of citizens. Constraints developed in the three submodels of this chapter function as confining system-wide enrollment by the availability of resources, social demands for educational services, and manpower requirements for an educated and trained work force. Expressed mathematically, the objective function is

$$\max Z = \sum_i \sum_j P_{ij} \, , \qquad (3.21)$$

where

P_{ij} is the number of FTE students enrolled at institution i in program j for future time t.

Maximizing system-wide enrollment may at first appear to be a peculiar choice for the objective function. For example, writing the model in a form where the objective function minimizes system expenditures subject to minimal standard enrollment, space use, student demand, and manpower requirements conditions may appear more appropriate. The same end, however, is achieved in the model as derived. An objective function of the form used also facilitates the analysis of the ideal situation where exactly the right amount of money, facilities, and students exist for each program and each institution to meet state manpower requirements in an optimal manner.

Summary

The model developed in this chapter used an objective function that maximized system-wide enrollment for some future time. Three submodels were developed to facilitate the development of relations that were used to constrain institution enrollments. The first submodel involved the determination of the probable student demand. A number of policy actions taken at either the state or institution level were mathematically related to a probable student demand calculation as a means for controlling program enrollments. The second submodel described how occupation demand forecasts were obtained and integrated into the model. The last submodel related occupations and educational programs through the development of a student flow matrix. The manpower requirements for graduates of particular educational programs formed constraint relations. A summary of the model variables, defining equations, constraint equations, and objective function is given in Appendix A.

The model developed was applied to the analysis of the registered nurse programs in Florida's community college system using three registered nurse manpower requirements scenarios in the next chapter. As this was only a partial implementation of what would be required for meaningful results, the exercise was in reality a demonstration of the model procedures and feasibility.

CHAPTER IV
A LIMITED APPLICATION OF THE MODEL

Introduction

The model developed in Chapter III was applied in a limited fashion to the 21 public community colleges in Florida that offered complete registered nurse (RN) programs in 1980. The emphasis in this chapter was on implementation and analysis procedures which served to demonstrate how the model could be used as a planning tool. Since this was only a partial implementation of the model, a number of the defining and constraint equations developed in the previous chapter were necessarily modified. Strategies developed in response to various 1985 RN occupation demand scenarios that could be directly applied to the Florida community college system in 1980 were not the primary interest and should be viewed accordingly.

An initial step required in setting up a linear programming model involves determining the form of the constraint equations and estimating the constraint and objective function parameter values. Recall that the standard form of a linear program from Chapter II is

$$\text{Maximize } Z = cx \text{ ,} \qquad (2.1)$$

subject to

$$Ax \leq b \, , \tag{2.2}$$

and

$$x \geq 0 \, , \tag{2.3}$$

where the x matrix is comprised of the model decision variables and the c, A, and b matrices contain the model parameters. In the notation developed in Chapter III, the P_{ij}'s are the decision variables and comprise the x matrix. The A matrix contains the parameters c_{ij}, a_{ij}, and $r_{ij}a_{jk}(i,l)$ and the b matrix contains the F_i, C_{ij}, A_{ij}, and J_{kl} parameters. When applied to the 21 Florida community colleges that offered complete RN programs in 1980, the model in standard form reduced to

$$\text{Maximize } Z = \sum_{i=1}^{21} P_{i\,12303010} \, , \tag{4.1}$$

subject to

$$P_{i\,12303010} \leq F_{i\,12303010} \, , \tag{4.2}$$

$$P_{i\,12303010} \, c_{i\,12303010} \leq C_{i\,12303010} \, , \tag{4.3}$$

$$P_{i\,12303010} \, a_{i\,12303010} \leq A_{i\,12303010} \, , \tag{4.4}$$

$$\sum_{i=1}^{21} r_{i\,12303010} \, P_{i\,12303010} \, a_{12303010\,k} (i, 075) \leq J_{k\,075} \, , \tag{4.5}$$

and

$$P_{i\,12303010} \geq 0 \, . \tag{4.6}$$

Here, j = 12303010 was the community college Information Classification Structure (ICS) number for RN programs offered in Florida community colleges in 1980 (see Florida Department of Education, Division of Community Colleges, 1977a, pp. 2.1-2.8). The DOT (*Dictionary of Occupational Titles*, U. S. Department of Labor, 1977) number used for the RN occupation was i = 075 (p. 58).

The first section of the chapter deals with how all parameter values in equations 4.2 through 4.5, except the $C_{i\,12383818}$ parameters in equation 4.3 were derived. The $C_{i\,12383818}$ parameters were derived to respond to three alternative future RN occupation demand scenarios.

Three RN occupation demand scenarios were constructed from RN manpower requirements projections for Florida obtained by a model developed for the Division of Nursing by Vector Research, Incorporated (U. S. Department of Health, Education, and Welfare, 1978). The model considered

> three major anticipated changes in the health care system: the introduction of national health insurance [NHI], the increased enrollment in health maintenance organizations [HMO], and the reformulation of nursing roles. (p. 111)

The three scenarios were incorporated into the model through the $J_{k\ 075}$ parameters in equation 4.5.

In the second section of the chapter, effects were investigated on how well the anticipated 1985 RN social and economic demands are met by the Florida community college system. Funding strategies were represented in the model by the $C_{i\,12383818}$ parameters in equation 4.3.

Parameter Determination

The Supply of Graduates Submodel

The first step in forecasting the supply of RN program graduates in 1985 from Florida community colleges involved the estimation of the probable student demand for RN programs in 1985 by institution. As described in Chapter III, equation 3.1 provides the total anticipated demand for educational services from a particular institution at some future time. It does not function to the program level. Approximations of RN program probable student demands were obtained by taking the 1978-79 RN program enrollments from the AA-1 reports for all the community colleges (Florida Department of Education, Division of Community Colleges, 1980a) and multiplying the figures by a constant factor of 1.5. The constant factor, in this case, was purely an estimation based on discussions with Division of Community Colleges staff on the average system-wide RN application to enrollment ratio. The major assumption was, therefore, that the social demand for RN program enrollment in 1985 for each of the community colleges offering complete RN programs in 1980 will be 1.5 times greater than 1978-79 enrollments. It was also assumed that new RN programs would not be started in the community college system prior to 1985.

Converting the headcount demand to FTE demand was accomplished through equation 3.7 with the program to headcount ratios, the g_i's, set equal to one. The assumption was that RN program students at the community colleges have taken and will continue through 1985 to take an average of 30 semester credit hours a year. The $F_{i\ 12382010}$ values used for constraint equation 4.2 for all 21 community colleges are summarized in Table 10

In calculating the parameter values of the student access control constraints described by equations 4.3 and 4.4, Division of Community Colleges and Office of Facilities Construction data were used. Cost per RN FTE parameter values, or the $c_{i\ 12382010}$ parameters in equation 4.3, were derived as the sum of the 1978-79 instructional and support costs per RN FTE. Instructional cost data were obtained from the 1978-79 CA-3 reports for each community college (Florida Department of Education, Division of Community Colleges, 1980c). Since the CA-3 reports provided cost information by courses, it was necessary to compile the RN major required courses for each community college from the institution's catalog. The number of credits for each course was multiplied by the CA-3 report cost per student figure. Once the total institutional course cost per student was calculated by summing the individual course instructional costs, it was necessary to average the cost on a per year basis and then normalize the cost per student to a cost per FTE. Table 8 summarizes the procedure for one community college.

Once the instructional costs per FTE were calculated, physical plant, institutional, student services, and academic

Table 8
RN Program Total Instructional Cost/FTE
For Polk Community College

Required Courses	Credits	Total Cost/ Credit for Instruction	Total Course Cost for Instruction per Student
APB 2190	5	$58.21	$291.05
2191	5	56.45	282.25
ENC 1103	3	53.79	181.37
HUM. ELECTIVE	3	43.66	148.04
MCB 2013	5	54.11	270.55
MTB 1320	1	60.00	60.00
NUR 1211	10	74.25	742.50
1220	5	79.44	397.20
1620	1	63.75	63.75
2111	5	70.52	352.60
2120	5	54.71	273.55
2231	11	78.13	858.43
2622	1	67.45	67.45
NUR 1140	9	90.97	818.73
P.E. ELECTIVE	2	50.00	100.00
POS 1041	3	47.79	143.37
PSY 2000	3	53.58	160.74
SOC 1000	3	47.37	142.11
TOTAL	80		$5322

Average Instructional Cost per FTE per Year	$\frac{\$5322}{2} \times \frac{60}{80} = \$1996$

support costs per FTE were also added to obtain the $c_{1\ 12303010}$ parameter values for each community college. Data for the support costs were obtained from the Report for Florida Community Colleges 1978-79 (Florida Department of Education, Division of Community Colleges, 1980d, pp. 84-88). An example of how the $c_{1\ 12303010}$ parameter for a single community college was arrived at after adding support costs to the instructional cost is presented in Table 7. The assumption was made that the relative costs of different RN programs remained fixed through 1985.

To estimate the assignable square feet of space needed per RN FTE for each community college, the $a_{1\ 12303010}$ parameters in equation 4.4, two assumptions were made: (1) the RN FTE space requirements are the same system-wide, and (2) that the space requirement figures remain unchanged from 1980 through 1985. The occupational lab space factor derived by the Office of Facilities Construction for estimating facilities needs was used. The effect of the standard was to provide approximately 46 assignable square feet per occupational FTE (Florida Department of Education, Office of Facilities Construction, 1978, p. 2). The definition of annualized FTE used in the study has been 30 semester credit hours taken in one year, or a semester average of 15 hours. Dividing by five, the estimate of the number of contact hours per day was determined to be three. In one day, therefore, approximately 3 x 46 or 138 assignable square feet are consumed per RN FTE.

Table 7
Total Cost/FTE for the RN Program at Polk Community College
$C_{17\ 12363616}$

Instructional Cost/FTE
$1996

Physical Plant Cost/FTE
$183

Institutional Support Cost/FTE
$270

Student Services Cost/FTE
$158

Academic Support Cost/FTE
$123

Total = $C_{17\ 12363616}$ = $2730/FTE

The $A_{i\ 1,2,3\ldots28}$ parameter values for equation 4.4 were arrived at using 1978-79 RF-1 reports from each community college (Florida Department of Education, Division of Community Colleges, 1980e), a unit space analysis computer run on the current room inventory by the Division of Community Colleges, and in some cases community college facilities personnel were contacted directly. The gross RN space figures obtained were multiplied by seven to provide an estimation of the total RN assignable square feet of space available in a day. The assumptions were that RN facilities have been and will continue to be utilized at most seven hours per day through 1985 and that the RN space available in 1979 will remain fixed in terms of assignable square feet of space. Using the 1978-79 RF-1 report for Polk Community College produced the figures listed in Table 8.

The third step in the supply of graduates submodel was to estimate the number of graduates. To accomplish this, the $r_{i\ 1,2,3\ldots28}$ ratios in equation 3.15 were calculated using AA-1 reports for each community for each year from 1975-76 through 1978-79 (Florida Department of Education, Division of Community Colleges, 1977b, 1978, 1979, 1980a) A simple weighted average ratio of RN program completions to enrollments was used for the following reasons: (1) several RN programs were not in existence long enough to yield sufficient data entries to justify using the double exponential smoothing algorithm, (2) early RN enrollment figures skew a simple mean, and (3) inaccurate data. The

Table 8
Calculation of the Total Assignable Square Feet of Space for the RN Program at Polk Community College

Assignable Square Feet of Space Used by the RN Program at Polk Community College by Room			
1295	104	98	84
376	113	96	90
336	101	96	25
214	201	96	25
192	99	458	259
113	36	728	23
135	98	505	
96	98	45	
	Total ASF	6,369	
	A_{17} [illegible]	44,600	

last point is demonstrated by the fact that Division of Community Colleges data seldom agreed with National League for Nursing data for the same time periods (National League for Nursing, 1976, 1977, 1978, 1979). A demonstration of the ratio of the number of RN graduates to FTE calculation for one community college is displayed in Table 9. The assumption here was that the ratios as determined represent the 1985 conditions.

Table 9
Ratio of RN Graduates to RN FTE
for Polk Community College

Year (Y_m)	Y_1 1975-76	Y_2 1976-77	Y_3 1977-78	Y_4 1978-79
Completions	120	114	89	81
Enrollments	306	418	384	284
$\frac{\text{Completions}}{\text{Enrollments}}$ (U_m)	.39	.27	.24	.28
Weights (W_m)	1	2	3	4
$r_{17\ 12357810} = \frac{\sum_{m=1}^{4} U_m W_m}{10}$	.28			

A summary of all the parameters used in the supply of graduates submodel except the $C_{i\ 12357810}$ parameters is presented in Table 10. The $C_{i\ 12357810}$ parameters are specified in a later section and are used as the primary elements in

Table 10
Forecasting the Supply of Graduates Submodel
Parameter Summarization*

Community College (i)	g_i	F_i	r_i	c_i	a_i	A_i
1	1	310	.36	3250	138	48,400
2	1	323	.50	3820	138	83,400
3	1	255	.31	3080	136	20,700
4	1	471	.33	2860	138	31,500
5	1	209	.37	3350	136	20,700
6	1	809	.41	3140	138	123,700
7	1	146	.16	4050	138	11,100
8	1	275	.28	3400	138	14,500
9	1	808	.26	3840	138	100,200
10	1	149	.42	2770	138	19,600
11	1	171	.31	3010	138	21,800
12	1	416	.29	3200	138	87,300
13	1	855	.48	3350	138	137,500
14	1	479	.37	3190	138	120,200
15	1	123	.28	3000	138	25,300
16	1	521	.37	3000	138	67,800
17	1	441	.28	2730	138	44,800
18	1	787	.31	3180	138	140,800
19	1	630	.20	2990	138	116,800
20	1	96	.38	2880	138	17,900
21	1	417	.37	3720	138	149,800

*See Appendix 8 for the community college key.

the construction of system strategies in response to the various RN occupation demand scenarios described in the next section.

The Occupation Demand Submodel

Three occupation demand future scenarios were derived for Florida registered nurse needs for 1985 from existing federal registered nurse manpower requirements forecasts. The three scenarios were extracted from the study, The Impact of Health System Changes on States' Requirements for Registered Nurses in 1985 (U. S. Department of Health, Education, and Welfare, 1978).

The first scenario was the baseline scenario, defined as

> a conservative extrapolation of the present trends in health care to the 1985 time frame. For the most part, the configuration of the future health care system is assumed to be an extension of the recent past. For this reason no NHI [national health insurance] program is instituted, no HMOs [health maintenance organizations] are added, and limited reformulation in nursing roles is preserved under the baseline scenario.
>
> Thus, the baseline can be considered a very conservative, albeit possible, projection of the future requirements for RNs [registered nurses]. The degree to which it becomes a realistic projection is dependent on the degree to which the system changes investigated here occur, or the extent of other changes not foreseen or treated in this analysis. (U. S. DHEW, 1978, pp. 3-4)

The baseline scenario functioned as the gauge by which results generated in response to other scenario conditions were measured. The fact that the baseline scenario projected registered nurse (RN) needs for the future based on the conservative assumption that the leading factors that have determined RN manpower requirements allowed for the assessment of the effects of deviations from this assumption on future RN manpower requirements.

The major assumptions inherent in the baseline scenario follow:

1. A national health insurance program will not occur prior to 1985.
2. The health maintenance organizations in existence in 1974 will continue to grow at rates derived from historical data.
3. There will be no further acceptance of nursing role reformulation from the estimated 1972 level (HEW, 1978, pp. 3-4).

The second RN occupation demand future scenario was the national health insurance (NHI) scenario. The NHI scenario

> models the situation in which the uninsured portion of the population receives insurance benefits equivalent to those enjoyed by the insured population. This is intended to represent those NHI bills which guarantee some degree of protection to everyone and thereby plug the gap in current public and private insurance coverage. (U. S. DHEW, 1978, p. 11)

The NHI scenario was different from the baseline scenario only in terms of NHI parameters. The principal assumptions were:

1. The effective implementation year for national health insurance is 1979, and the total impact of NHI is expected to occur within two years, by 1981.
2. As uncovered individuals become covered, they consume health services at the same rate as those in their respective cohorts who previously had health insurance (U. S. DHEW, 1978, pp. 11-12).

The third RN occupation demand future scenario was the combination (COMB) scenario. The COMB scenario

> consists of the NHI . . . scenario with moderate HMO [health maintenance organization] growth and moderate acceptance of role reformulation concepts. (U. S. DHEW, 1978, p. 22)

The major assumptions different from the NHI scenario follow:

1. The rate of increase in the number of new HMO's per quarter will be identical to the average rate experienced between January 1974 and July 1975.
2. The percent of inpatient units in the country utilizing primary nursing grows linearly to 40 percent in 1985.
3. The number of clinical nurse specialists that would be in new roles by 1985 reaches 75 percent.
4. Demand for physicians' services in office visits satisfied by nurses in practitioner roles grows linearly to 65 percent by 1985 (U. S. DHEW, 1978, pp. 15-19).

In the 1978 HEW report, 1980 and 1985 Florida RN requirements for each scenario were projected RN manpower needs for full-time workers. The full-time figures were converted to headcount requirements utilizing a ratio reported in a latter HEW publication (U. S. DHEW, 1976, pp. 152, 158). Table 11 summarizes the scenario RN requirements for Florida in 1980 and 1985.

Table 11
Projected RN Requirements for 1980 and 1985 in Florida

Year	Baseline Scenario	NHI Scenario	COMB Scenario
1980	38,963	43,345	44,866
1985	49,662	53,848	56,995

In the next step, equations 3.16 and 3.17 were used to break down the state requirements into county units. For the baseline scenario, equation 3.16 is

$$\sum_{k=1}^{67} O_{k\ 075} = \frac{9699}{5} + \frac{89,625}{2} \times (.047) = 4046 ,$$

which represents the average number of total additional RN's needed each year in the five-year period from 1990 to 1995 in Florida. The annual net attrition rate value, d_{075}, of 4.7% for RN's was taken from a Florida Board of Regents' manpower study (1968, p. 12). Here, 67 is the number of Florida counties and 075 is the Dictionary of Occupational Titles, DOT, number for the registered nurse occupation. Medium midyear population projections by county were obtained from the Florida Statistical Abstract 79 (1979, pp. 11-16) and used in equation 3.17. Since a number of counties in Florida had relatively small populations and thus small RN yearly requirements, the number of counties specifically considered in the analysis was reduced from 67 to 28. Requirements from equation 3.16 for the 39 counties not specifically considered were summed and then evenly distributed to the 28 that were. For the baseline scenario, the total additional RN manpower requirements for 1995 by county k = 1,2,3,...,28 are summarized in Table 12. By a similar procedure, manpower requirements under the NHI and COMB scenarios were derived and are also listed in Table 12. A county key is supplied in Appendix B.

Table 12
1885 State RN Requirements

[illegible]	Baseline Scenario 0_k 075	NH1 Scenario 0_k 075	COMB Scenario 0_k 075
1	75	81	90
2	57	62	68
3	103	112	123
4	525	569	626
5	50	54	59
6	50	55	60
7	27	29	32
8	544	588	648
9	173	188	207
10	88	95	105
11	268	291	319
12	43	47	52
13	61	66	72
14	132	143	157
15	75	81	89
16	83	90	99
17	72	78	85
18	30	33	36
19	61	66	72
20	191	207	227
21	317	344	378
22	124	134	148
23	350	379	417
24	130	141	155
25	58	64	71
26	118	128	141
27	115	125	137
28	124	134	147

The anticipated need for public postsecondary education RN program graduates in 1985 were calculated from the data in Table 12 and by considering in-migration and private postsecondary education contributions to the RN work force in the form of equation 3.1%. The in-migration factor, m_{075}, was approximated using 1970 U. S. census data (U. S. Department of Commerce, 1973, pp. 66, 212). The number of in-migrants from 1965 to 1970 from different states and abroad to Florida was summed and then divided by the number of years over which the migration occurred. It was assumed the in-migrant population age distribution was similar to Florida's as a whole. The proportion of over 65-year-olds and under 20-year-olds was discounted, which left an approximate figure of how many able workers were available for employment. This figure was then simply divided by the number of DOT occupational groups to yield the average approximate number of RN's that in-migrated to Florida in any year in the period from 1965 to 1970. The quantity obtained was used as the total number of in-migrating RN's in 1985 to the state of Florida. It was further assumed that in-migrating RN's distributed evenly throughout the state. A figure of 5 was obtained for m_{075}.

The fraction of new 1985 RN positions expected to be filled by 1985 public community college RN program graduates, n_{075}, was derived utilizing National League for Nursing data from 1975 through 1979. To the nearest 10%, a mean figure of 70% was obtained for n_{075} (National League for Nursing, 1975, 1976, 1977, 1978, 1979). Table 13 summarizes the 1985 anticipated need for public community college RN program graduates for the RN occupation under three different scenario conditions.

The Student Flow Submodel

The parameters estimated in this section are the RN participation rates, the $a_{12345678\,k}$ (1,075) parameters, in equation 4.5. The 1978-79 AA-2 placements reports for each community college were surveyed and found inadequate for determining participation rates due to lack of detail concerning the occupations held by program graduates (Florida Department of Education, Division of Community Colleges, 1980b). The participation rates displayed in Table 14 were approximated by intuitive integration of past RN enrollments, county RN needs as a function of population, and the proximity of place of employment with community college. The emphasis was on accounting for the primary RN graduate flows. It was assumed that one year after graduation, approximately 80% of the RN program graduates from each community college find employment in the RN occupation in Florida and that this rate is constant over the planning period.

Summary

All parameters in equations 4.2 through 4.5 have been estimated except the $C_{i\,12345678}$ parameters. A number of simplifying assumptions were necessary due to the limited nature of the application example and to difficulties with

Table 13
1985 Requirements for Community College RN Program Graduates

[illegible] (k)	Baseline Scenario J_k 075	NSI Scenario $\hat{J}_k$ 075	COMB Scenario $\hat{J}_k$ 075
1	48	52	58
2	35	38	43
3	67	73	81
4	263	394	433
5	30	33	36
6	30	33	37
7	14	16	18
8	376	408	488
9	117	127	140
10	56	62	68
11	183	198	219
12	25	28	31
13	38	41	46
14	87	95	105
15	47	52	57
16	53	58	64
17	45	49	55
18	16	18	20
19	37	41	46
20	129	140	154
21	217	236	259
22	82	89	98
23	240	261	287
24	86	94	104
25	37	40	45
26	78	85	94
27	76	83	91
28	82	89	98

Table 14
Student Flow Matrix for
RN Program Graduates* **

County (k)	Community College (1)																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1																			.4		
2								8													
3	.6									.1											.1
4		.6											.1								
5					.1																
6											.2										
7											.3										
8		.1					.1						6	1					.1		
9						.6					.1								.1	.1	
10																.6					
11			.1						.6									.1	.1		
12										.3											
13		.2																			
14					.6																
15											.1									.6	
16												.2									
17			3																		
18							.6														
19								.1								.1					
20																	.1				.6
21						.1								.6							
22															.6						
23									1			1						.6			
24															.1		.6				
25										.3											
26												.4									
27			.1	3																	
28	.1			.4																	

*All non-specified matrix elements have a value of 0.004.
**Appendix B has community college and county keys.

data. In the next section, total cost parameters were designated as the primary model parameters used to depict alternative system strategies that respond to the three different RN occupation demand scenarios. With all other parameters held constant, the varying of the $J_{k\ 075}$ RN manpower requirements parameters constitutes a sensitivity analysis of the optimal distribution of RN program FTE's throughout Florida's community college system in 1985.

Results

Description

For the purposes of demonstrating how the model may be used as a planning tool for postsecondary education, six possible 1985 Florida community college system futures were considered dealing specifically with RN programs. The six futures were divided evenly into two broad categories. Three Series I futures represented situations where RN program costs, enrollments, and facilities parameters were determined solely by the anticipated 1985 RN manpower requirements scenarios. Series I futures were determined by normative futures forecasting techniques and were defined as the most desired, or ideal system future states. Three Series II futures integrated anticipated RN enrollments and facilities parameters, determined by explorative futures forecasting trend analysis methods, with anticipated 1985 RN manpower requirements scenarios. Series II futures represented simple projections of 1980 trends into the future.

In this section, analyses of the baseline, NHI, and COMB 1985 RN manpower requirements scenarios within Series I and Series II Florida community college RN program scenarios are presented. The community college scenarios developed included community college RN program enrollment, facilities, and expenditure dimensions. Since Series I enrollment, facilities, and expenditure parameter values characterized the most desired system future states, strategies were developed for each community college RN program that specify what modifications are needed to increase the probability that a Series I future will occur and decrease the probability that the corresponding Series II future will occur. In Appendix C, the Series II baseline scenario future is provided for reference.

Enrollment Analysis

The analysis of the anticipated 1985 RN program enrollments at Florida's community colleges consisted of comparing Series I and Series II enrollments with each other and with the probable student demand figures derived in the previous section. Series I enrollments were obtained by letting the parameters in equations 4.2, 4.3, and 4.4 corresponding to the b matrix elements in equation 2.2 be free variables, thus allowing the remaining model constraint determine their values. Series II enrollments were obtained by using the parameter values determined in the previous section, letting only the total cost parameters, the $C_{1,2,3,\ldots,10}$, be free variables.

In Table 15, the results of Series 1 and Series 11 conditions on enrollments are depicted. Comparing Series I enrollments with the anticipated demand, only the anticipated demand figure for community college 17 occurred between its Series I enrollment bounds. The anticipated student demand at school 17 therefore coincides with what will be needed. Approximately 38% of the schools have ideal Series 1 enrollments less than their anticipated demands while at 57% of the schools, the demand is less than the enrollment need.

The most severe differences between anticipated student demand and Series 1 enrollments occur at schools 2, 6, 7, 11, and 15. The Series 1 enrollment needs for schools 2 and 15 range from 2.1 to 4.3 times the anticipated student demand. This means that unless the schools take measures to change the anticipated student demand for RN programs in 1985, serious discrepancies will exist between the number of students wanting to enter RN programs at these schools and the number of students needed in the programs to meet area manpower requirements. At schools 6, 7, and 11, more students are anticipated to want to enter RN programs in 1985 than are needed to fill area manpower requirements. The anticipated student demand for the schools range from 1.8 to 10.7 times the Series 1 enrollment needs. Since

Table 15
Series I and II
1985 RN Enrollment Analysis (FTE)*

Community College	Anticipated RN FTE Demand	Series I RN FTE Enrollment			Series II RN FTE Enrollment		
		Baseline	NHI	COMB	Baseline	NHI	COMB
1	310	155	187	187	177	201	237
2	323	663	1,114	1,224	323	323	323
3	255	269	283	321	150	150	150
4	471	481	528	581	228	228	228
5	209	338	367	405	150	150	150
6	809	368	387	437	382	416	480
7	148	37	40	46	72	80	80
8	275	135	143	164	105	105	105
9	608	794	856	947	608	608	608
10	149	100	111	124	128	142	142
11	171	16	20	28	53	73	92
12	418	570	617	682	416	418	416
13	855	1,017	1,040	1,140	855	855	855
14	479	862	931	1,028	479	478	479
15	123	448	483	532	123	123	123
16	521	197	217	238	213	239	285
17	441	373	406	450	323	323	323
18	797	1,036	1,127	1,238	737	797	797
19	830	448	478	535	481	539	512
20	96	146	160	175	96	98	96
21	417	483	521	573	417	417	417
Totals	8,501	8,968	10,006	11,051	6,587	6,760	6,958

*A community college key is provided in Appendix B.

Series I enrollment needs at schools 7 and 11 are very low, the possibility of phasing RN programs out of these schools must be a consideration.

Series II enrollments were limited in 13 schools by the anticipated student demand. Twelve of these schools corresponded to Series I schools that needed to act on increasing their 1985 anticipated student demand. Only five schools had a Series II enrollment range that overlapped their Series I enrollment range. If the trend extrapolation enrollments represented by Series II figures persisted in 1985, the anticipated RN student demand will not be met.

System totals show the average Series I enrollment need to be 18% greater than the anticipated student demand. The Series II enrollment need, however, is 20% less than the anticipated student demand. In sum, 38% fewer RN FTE's are expected by trend extrapolation in 1985 than are expected to be needed in Florida's community college system to meet the state's RN manpower requirements.

Space Analysis

The total 1985 anticipated RN program space for a seven hour day for each community college, you may recall, was taken to be equal the RN program space provided in the 1978-79 academic year. Comparisons of the Series I and Series II space needs with the anticipated available RN space were made from Table 16 data.

The anticipated available spaces at only community colleges 12 and 14 were within their Series I ranges. Eleven

Table 16
Series I and II
1985 RN Program Space Analysis
(daily assignable square feet x 100)

Community College	Anticipated RN Space	Series I RN Space			Series II RN Space		
		Baseline	NBI	COMB	Baseline	NBI	COMB
1	464	214	230	258	244	277	327
2	634	843	1,537	1,889	446	446	446
3	207	371	391	442	207	207	207
4	315	677	729	802	315	315	315
5	207	466	506	559	207	207	207
6	1,237	508	548	603	527	574	635
7	111	50	55	63	100	111	111
8	145	136	187	226	145	145	145
9	1,002	1,095	1,182	1,307	839	839	839
10	196	139	154	171	177	196	196
11	216	22	28	36	74	100	127
12	873	787	851	942	574	574	574
13	1,375	1,403	1,435	1,574	1,180	1,180	1,180
14	1,202	1,189	1,284	1,415	661	661	661
15	253	619	886	734	170	170	170
16	678	272	299	328	294	330	366
17	446	515	580	621	446	446	446
18	1,409	1,433	1,556	1,709	1,100	1,100	1,100
19	1,166	618	659	738	678	744	844
20	179	202	221	241	132	132	132
21	1,498	686	718	780	575	575	575
Totals	13,813	12,375	13,807	15,248	9,091	9,329	9,803

schools needed more space than was anticipated to be available while 8 had Series I space needs less than their anticipated space. Of these last 19 schools, 8 had Series I space needs within 13% of their anticipated available space.

The most severe Series I space shortages occurred at community colleges 2, 3, 4, 5, 8, and 15. Individual space increases of between 28% and 168% existed above the anticipated space levels.

Space surpluses ranging from 37% to 90% of the anticipated space occurred at schools 1, 6, 7, 11, 18, 19, and 21. In a full scale model application, space surpluses occurring in one program area would be consumed by programs showing space shortages.

A Series II space needs comparison with the anticipated available space showed 67% of the community colleges needed less than their anticipated space supply. Fourteen schools did not need all the space they had available provided Series II conditions prevailed in 1985.

System totals show that the 1985 average total systemwide Series I space need for RN programs in Florida's community colleges equaled the total anticipated RN space available. The problem was, of course, redistributing this total anticipated space in the pattern of Series I space needs. Total Series II space need was 33% less than the anticipated RN space for 1985. If Series II conditions are maintained, one third of the system's RN anticipated space, therefore, would not be needed in 1985.

Cost Analysis

The total program cost parameters for Series I and Series II for each community college, you may recall, were allowed to be free variables. In the Series I situation, the RN program costs listed in Table 17 depict 1985 dollar amounts necessary to insure scenario manpower requirements for community college trained RN's are met. Series II program costs represented the ideal dollar amounts needed if space, student demand, and manpower requirements constraints were specified. Only in the situation of program quality improvement could an expenditure beyond the Series I or Series II recommendation be justified.

Since the costs listed are in 1979 dollars, the figures themselves are meaningless as forecasts of the actual 1985 program costs for each institution. Only relative differences between community colleges within each series situation or between series, therefore, were investigated.

A wide range of Series I program costs for community colleges constrained by three different RN manpower requirements scenarios existed. The maximum COMB program cost was greater than 30 times the minimum baseline program cost.

The five highest cost programs under the baseline scenario in descending cost magnitude are at schools 13, 15, 9, 14, and 2. If the COMB scenario manifests itself, the order of the schools with the highest program costs changes to 2, 15, 13, 9, and 14. School 2 shows an estimated 79% increase in the Series I baseline to COMB scenario

Table 17
Series I and II
1985 RN Program Cost Analysis
(1979 dollars x 100)

Community College	Series I RN Program Cost			Series II RN Program Cost		
	Baseline	NHI	COMB	Baseline	NHI	COMB
1	6,042	5,428	6,066	5,746	6,535	7,709
2	24,736	40,316	44,318	11,693	11,683	11,683
3	8,283	8,721	9,872	4,620	4,620	4,620
4	14,131	15,220	16,732	6,574	6,574	6,574
5	11,315	12,280	13,577	5,025	5,025	5,025
6	11,555	12,473	13,723	11,967	13,052	14,439
7	1,479	1,828	1,858	2,931	3,258	3,258
8	4,581	4,856	5,577	3,572	3,572	3,572
9	30,476	32,880	36,358	23,347	23,347	23,347
10	2,781	3,082	3,425	3,543	3,934	3,934
11	487	601	779	1,608	2,191	2,767
12	18,247	19,737	21,839	13,312	13,312	13,312
13	34,087	34,841	38,198	28,642	28,642	28,642
14	27,485	29,683	32,718	15,280	15,280	15,280
15	13,452	14,487	15,947	3,680	3,680	3,680
16	5,916	6,507	7,125	6,380	7,167	7,850
17	10,190	11,088	12,287	8,823	8,823	8,823
18	33,012	35,850	39,370	25,345	25,345	25,345
19	13,396	14,263	15,997	14,688	16,113	18,286
20	4,213	4,614	5,031	2,765	2,765	2,765
21	17,957	18,385	21,302	15,512	15,512	15,512
Totals	282,801	327,983	382,089	215,081	220,450	226,543

transition while the increases for the other four schools range from 12% to 19%.

The five community colleges with the smallest Series I program costs under the baseline scenario in the order of increasing costs were schools, 11, 7, 10, 20, and 8. Under the COMB scenario, the same schools in the same order had the smallest program costs.

The Series II program cost range was narrower than the Series I. The maximum COMB scenario program cost was 18 times the minimum baseline cost, a factor of five less than the Series I range.

Greater stability existed among the highest cost programs in the Series II situation between the baseline and COMB scenarios. The six highest cost baseline scenario programs in the order of decreasing costs were at schools 13, 18, 9, 21, 14, and 19. Under the COMB scenario, the order changed to 13, 18, 9, 19, 21, and 14.

The five Series II schools with minimum program costs under the baseline scenario in the order of increasing costs were at community colleges 11, 20, 7, 10, and 8. COMB scenario schools with the smallest program costs were 11, 20, 7, 8, and 15.

Comparing Series I program costs with Series II costs revealed that only community colleges 1, 6, 16, and 19 had Series I program cost ranges that overlapped their corresponding Series II cost ranges. Schools 7, 10, and 11 had Series I cost ranges below their Series II ranges. The remaining 14 schools had Series I cost ranges above their corresponding Series II ranges. The five schools with the greatest discrepancies between their Series I and Series II program cost needs were 15, 2, 5, 4, and 14. The average costs for school 15 for the two series situations differed by a factor of four. In sum, wholly two-thirds of the community colleges needed to make efforts to increase RN program funds in order to move from the highly probable 1985 trend determined Series II situation toward the ideal Series I situation

System-wide, the total Series I program cost increased 24% from the baseline to the COMB 1985 RN manpower requirements scenario. For Series II, the increase was only 5%. The average total Series II system program cost was just 67% of the system average needed for the ideal Series I situation. In conclusion, the Series II cost projections at the system-level indicated that a serious under-funding of RN programs in 1985 would exist and that the more liberal RN manpower requirements scenarios considered produced even more pronounced discrepancies.

Requirements Analysis

The baseline, NHI, and COMB 1985 RN manpower requirements scenarios depicted in Table 12 indicate the ideal number of community college RN program graduates needed by county area to meet 1985 statewide needs. In this section, Series II RN program graduates anticipated from Florida's community colleges in 1985 that entered the RN occupation work force by county were analyzed for each manpower requirements scenario. How closely the Series II figures approached the scenario requirements indicated to what degree the economic demands for 1985 RN program graduates were satisfied.

The Series II baseline scenario RN production from the community colleges in 1985 distributed to the 28 county areas as displayed in Table 18. Eight counties had their 1985 RN manpower requirements met. They were counties 1, 3, 4, 7, 8, 10, 12, and 18. Shortages occurred in the remaining 20 counties. Less than half the needs for 1985 community college RN graduates were satisfied in counties 5, 6, 14, 22, and 27 The most severe situation in terms of the percentage of unmet manpower need existed in county 22 where 66% of the 1985 RN need for 1985 community college RN graduates was not met. The largest number shortage occurred in county 21 where 87 additional 1985 community college RN graduates were needed.

The state total for the Series I RN production satisfied 87% of the baseline requirements. This was not 100% since the student flow matrix parameters were crude approximations. The small discrepancy, however, proved to be consistent throughout the occupation demand scenarios and therefore did not adversely affect results

The baseline Series II statewide total of 1985 community college RN program graduates entering Florida's RN work force in 1985 was 1,832. The number needed was 2,584

Table 18
Series I and II
1985 Baseline Scenario RN Requirements Analysis

County	Baseline RN Requirements	Series I RN Production	Series II RN Production
1	48	48	48
2	35	35	27
3	87	67	87
4	263	263	263
5	30	26	14
6	30	13	12
7	14	14	14
8	378	378	297
9	117	117	117
10	58	58	56
11	183	183	141
12	25	25	25
13	38	38	23
14	87	87	42
15	47	47	33
16	53	45	33
17	45	37	23
18	16	16	16
19	37	23	19
20	129	128	110
21	217	217	130
22	82	82	28
23	240	240	183
24	86	86	66
25	37	25	25
26	78	78	57
27	76	68	36
28	82	82	45
Totals	2,594	2,523	1,832

Only 71% of the demand for 1985 community college RN program graduates was satisfied under the Series II baseline scenario.

Series I NHI scenario results are presented in Table 19. In the NHI scenario, the number of counties that had their 1985 RN manpower requirements met was five, three less than in the Series II baseline scenario. They were counties 1, 3, 7, 9, and 10. For counties that had RN manpower shortages, the number that had less than half their 1985 RN manpower requirements met increased from five in the baseline scenario to seven. These hard hit counties were 4, 5, 6, 14, 17, 22, and 27. The greatest percentage of unmet manpower need occurred in county 22 where 68% of the 1985 RN requirement for 1985 community college RN program graduates was not filled. The largest number shortage existed in county 4 where 249 additional 1985 community college RN program graduates were needed.

The NHI scenario Series II statewide total of 1985 community college RN program graduates that entered the RN occupation in Florida in 1985 was 1,876. The number needed was 2,932. Under the Series II NHI scenario, the shortage of RN program graduates intensified from the baseline scenario. Where 71% of the demand was met in the baseline scenario, 64% was met in the NHI scenario.

The Series II COMB scenario RN requirements data are summarized in Table 20. The number of counties having their 1985 RN manpower requirements met remained unchanged from the NHI scenario. They were counties, 1, 3, 7, 9, and 10.

Table 19
Series I and II
1985 NHI Scenario RN Requirements Analysis

County	NHI RN Requirements	Series I RN Production	Series II RN Production
1	52	52	52
2	38	38	27
3	73	73	73
4	394	394	145
5	33	27	15
6	33	15	14
7	16	16	16
8	408	408	298
9	127	127	127
10	62	62	62
11	198	198	142
12	28	28	27
13	41	41	24
14	95	95	42
15	52	52	34
16	58	49	33
17	49	40	23
18	18	18	17
19	41	26	21
20	140	140	110
21	235	235	131
22	89	88	28
23	261	261	183
24	94	94	86
25	40	28	27
26	85	85	57
27	83	74	38
28	89	89	48
Totals	2,932	2,854	1,876

Table 20
Series I and II
1985 COMB Scenario RN Requirements Analysis

County	COMB RN Requirements	Series I RN Production	Series II RN Production
1	58	58	58
2	43	43	27
3	81	81	81
4	433	433	145
5	36	30	15
6	37	17	15
7	18	18	18
8	448	448	300
9	140	140	140
10	68	68	88
11	219	219	144
12	31	31	27
13	46	46	24
14	105	105	43
15	57	57	35
16	64	54	33
17	55	45	23
18	20	20	17
19	46	28	22
20	154	154	110
21	259	259	133
22	98	98	29
23	287	287	184
24	104	104	67
25	45	31	27
26	94	94	57
27	91	82	36
28	98	98	48
Totals	3,235	3,158	1,826

The number of counties out of the remaining 23 with unmet RN manpower needs that had less than half of their needs for 1985 community college RN program graduates satisfied continue to increase in the COMB scenario. In the baseline scenario, five counties had less than half their needs met, while in the COMB scenario, the number was nine The nine counties with severe RN shortages were counties 4, 5, 6, 14, 17, 18, 22, 27, and 28. County 22 had the greatest percentage of unmet manpower need where 70% of the 1985 community college RN program graduates requirement went unfilled. County 4 had the largest number shortage of RN's where 288 additional 1985 community college RN program graduates were needed.

The number of 1985 community college RN program graduates that entered the RN profession in 1985 in Florida totaled 1,928 in the Series 1 COMB scenario. The number needed was 3,235. The shortage of RN program graduates continued to worsen from the baseline scenario where 29% of the demand went unfilled to the COMB scenario where the figure increased to 40%. Indeed, the community college system had increasing difficulty in producing adequate numbers of RN graduates the more the RN manpower requirements deviated from the baseline scenario.

Strategy Development

The major emphasis of the chapter to this point was to demonstrate how the model combines the exploratory and normative futures forecasting approaches is suggesting strategies that prevent or achieve trend analysis system future states or adapt to more desirable inventive system future states. The first section specified student demand, RN program space, and RN manpower requirements constraint parameter values used in the trend analysis 1985 long-range forecast involving Florida's community college RN programs. Ranges on the trend analysis forecast were derived from using three alternative 1985 RN manpower requirements scenarios. The trend analysis system future states were labeled Series II futures.

The inventive future system states were labeled Series I futures. Student demand, RN program space, and RN program cost constraint equation maximum limits were totally relaxed and determined solely by the three alternative 1985 RN manpower requirements scenarios. The three manpower scenarios again set ranges on the Series I futures. Series I futures specify the desired system futures states.

In the results section, it was shown to what extent the RN programs in Florida's community college system had to change by 1985 in order to go from Series II futures to Series I futures. Table 21 summarizes the primary limiting constraints for each RN program Series II future. The primary limiting constraint was the first constraint encountered that capped the RN FTE enrollment at a particular community college. Ideally, the primary limiting constraint desired was requirements. The RN program expenditures,

Table 21
Series II Primary Limiting Constraints

Community College	Baseline	NB1	COMB
1	requirements	requirements	requirements
2	demand	demand	demand
3	space	space	space
4	space	space	space
5	space	space	space
6	requirements	requirements	requirements
7	requirements	space	space
8	space	space	space
9	demand	demand	demand
10	requirements	space	space
11	requirements	requirements	requirements
12	demand	demand	demand
13	demand	demand	demand
14	demand	demand	demand
15	demand	demand	demand
16	requirements	requirements	requirements
17	space	space	space
18	demand	demand	demand
19	requirements	requirements	requirements
20	demand	demand	demand
21	demand	demand	demand

available facilities space, and RN student demand should ideally be just enough to enable the requirements constraint to be the primary limiting constraint.

The first point of interest concerning the primary limiting constraints listed in Table 21 is the stability of the constraints across the three manpower requirements scenarios. Only schools 7 and 10 had primary limiting constraints that changed. Primary limiting constraints were not, therefore, particularly sensitive to the manpower requirements in the baseline, NHI, and COMB scenarios.

Since the objective was to reach the point where RN manpower requirements were the primary limiting constraints and since Table 21 indicates that only five community colleges had requirements as their primary limiting constraints through the scenario ranges, a significant amount of modification was necessary before Series 1 futures could be approached. Even the schools with requirements listed in Table 21 as their primary limiting constraints needed space and demand changes to avoid wasting these resources. For example, community college 11 has requirements listed as its primary limiting constraint in Table 21. Yet from Table 15 and Table 16, both demand and space anticipated in 1985 required considerable reduction to be more in line with the Series 1 recommended value ranges for demand and space. An initial step in developing strategies that prevent Series II futures and aid attaining Series 1 futures was the determination of the extent to which space and demand needed to be reduced for schools having requirements as their primary limiting constraint in Table 21.

A community college that listed demand or space in Table 21 as a limiting constraint needed to increase the constraint value to its Series 1 level. This eliminated the constraint from preventing the school from satisfying state manpower requirements for its RN program graduates. In the case of community college 21, demand needed to be increased to a value in the range of its Series I enrollments in Table 15. Once demand was satisfied, the objective of having requirements as the new primary limiting constraint was attained. Checking the space constraint at this point, Table 18 reveals that to prevent wasting space, the 1985 anticipated available space for the RN program was excessive and needed reduction.

Not all community colleges had requirements as a new primary limiting constraint after their Table 21 primary limiting constraints were eliminated. For example, once community college 2 had demand satisfied, space became the new primary limiting constraint. In sum, both student demand and facilities space were inadequate in the Series II futures to enable school 21 to meet state needs for its 1985 RN program graduates. Table 22 lists the Series II secondary limiting constraints defined to be the constraints that limit community college RN FTE enrollment at individual institutions after the non-requirements primary limiting constraints are eliminated in Table 21. Combining Table 21

Table 22
Series II Secondary Limiting Constraints

Community College	Baseline	NSI	COMB
1	requirements	requirements	requirements
2	space	space	space
3	demand	demand	demand
4	demand	demand	demand
5	demand	demand	demand
6	requirements	requirements	requirements
7	requirements	requirements	requirements
8	requirements	requirements	requirements
9	space	space	space
10	requirements	requirements	requirements
11	requirements	requirements	requirements
12	requirements	space	space
13	space	space	space
14	requirements	space	space
15	space	space	space
16	requirements	requirements	requirements
17	requirements	requirements	demand
18	space	space	space
19	requirements	requirements	requirements
20	space	space	space
21	requirements	requirements	requirements

and Table 22 makes it possible to determine which community colleges face future shortages and/or surpluses of student demand and facilities space regarding RN programs. In this fashion, specific strategies for each community college may be formulated.

Summary

The limited application of the model to the RN programs in Florida's community college system revealed that with a number of simplifying assumptions the results obtained could be used to formulate strategies that adapt to, prevent, or achieve a possible system future. The most serious parameter estimations occurred when approximating the student flow matrix for RN program graduates.

Specific results for community college RN programs indicated that a shortage of RN 1985 program graduates existed under a trend analysis 1985 projection of 1980 conditions. The shortage increased disproportionately as more liberal 1985 RN manpower requirements scenarios were considered.

CHAPTER V
SUMMARY

Summary and Discussion

This study presents the results of an initial research effort in the development of a statewide planning model for public postsecondary education. A prototype linear programming model was developed as a tool to assist state postsecondary education planners maximize selected system-wide policy objectives. The model could be used to generate alternative futures to aid state-level planners formulate strategies that adapt to, prevent, or achieve a possible system future. The focus of the model was not to predict the future, but rather to facilitate anticipation of many futures and the preparation of alternative strategies in response to variable system conditions such as enrollment, social demands for educational opportunities, resource allocation patterns, and manpower requirements.

The primary model constraint factors which functioned to determine the future program enrollments at postsecondary education institutions were student demand, available state resources, and manpower requirements. How these constraint factors are interrelated is presented schematically in Figure 6.

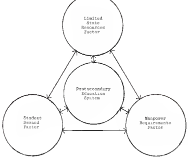

Figure 6. Model Constraint Factors

The student demand factor reflected the importance of integrating the need to keep postsecondary education accessible to a state's citizenry. The goal of public postsecondary education in the United States has historically been toward providing educational opportunities to the masses that elitist private institutions would not or could not provide. A system-wide plan that neglects considering this dimension of postsecondary education is really no plan at all.

The state resources factor consisted of two limiting constraint sets. The first related to postsecondary education appropriations, the second related to instructional facilities. Both constraints were developed to parallel the three-tiered control/planning mechanism within the state postsecondary education systems after Heigham (1969, pp. 300-304). With feedback processes implied, the mechanism of control and planning is schematically represented in Figure 7. Equations 3.11 and 3.14 represent the total money allocated and facilities supported for the postsecondary education system at the state political level respectively. Equations 3.10 and 3.13 represent the fact that the sum of the money and space allocated to each postsecondary education institution in a state through the postsecondary education coordinating/governing board or boards must be less than the totals of these two resources that were provided by the state. Lastly, equations 3.9 and 3.12 state that the amount of money and space consumed by a particular

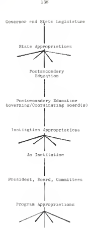
Governor and State Legislature
State Appropriations
Postsecondary Education
Postsecondary Education Governing/Coordinating Board(s)
Institution Appropriations
An Institution
President, Board, Committees
Program Appropriations

Figure 7. Three Tiers of the Limited State Resources Constraints

program at an institution cannot exceed the amounts budgeted for that program by the institution. By their very simplicity, these model constraints allow for testing any set of if-then cost and space conditions at the specific control/planning level where the conditions are most likely to occur.

The third and final primary model constraint factor was the manpower requirements factor. This constraint factor corresponds to the manpower approach of mathematical programming models in education described by Correa (1975, p. 29). The overriding interest in developing constraints here was that a postsecondary education system should incorporate into its planning routine the economic needs for an educated work force of specific composition. The very fact that both students and state funds earmarked for postsecondary education systems are scarce resources dictates that economic demands for graduates from particular programs be an integral part of responsible educational planning.

With some modifications, limited application of the model was accomplished using the registered nurse, RN, programs offered in Florida's community college system. A set of three future scenarios for 1985 based on trends identifiable in 1980 were devised to determine the 1985 manpower requirements for community college RN program graduates by state geographic area. Each of the three manpower scenarios was applied to two different community college 1985 scenarios.

The first community college RN program scenario, Series I, was a normative scenario which described 1985 community college RN programs as having the freedom to satisfy the manpower requirements optimally. By the application of three RN manpower scenarios, parameter ranges were determined for the resulting ideal community college RN program scenario futures.

The second community college RN program scenario, Series II, was an exploratory scenario which described the 1985 community college RN program condition based on 1980 trends. Again, parameter ranges for the resulting straight-line projection scenario futures were determined by the application of the three RN manpower scenarios.

In sum, six different 1985 futures were investigated. The object of the analysis was to compare Series I and Series II futures to determine the primary and secondary constraints in the Series II futures that prevented the community college RN programs in 1985 from attaining the ideal Series I futures. Strategies were then suggested from the results. Figure 8 summarizes the model application procedure.

The model, when applied to the limited situation, yielded results that appeared tenable. The fact that some data required for the model had to be approximated demonstrated the nature of the data problems that have confronted mathematical planning models in education. Indeed, Harcleroad (1971, pp. 34-38), Krause (1979, pp. 80-81), McNamara (1971, pp. 8-9), and McTarnaghan (1974, pp. 28-29) have all stressed

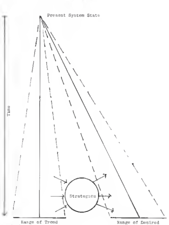
Present System State
Time
Strategies
Range of Trend Analysis Future States
Range of Desired Future States

Figure 8. Developing Strategies from Model Results

the need for the creation and maintenance of comprehensive, accurate management information systems prior to any postsecondary education system modeling effort. By using a series of manpower scenarios which in effect functioned to specify ranges for the two community college scenarios, effects of imprecise input data were diminished.

The major strengths of the model include a high level of tractability, ease in modeling any number of scenarios for analysis, low cost, and applicability to other state postsecondary education systems. Model weaknesses are that stochastic processes were not considered, some postsecondary education system data needed for the model may not be routinely collected in some states, the model is dependent on extensive manpower requirements forecasts from other governmental or private sectors, and to be effective the model needs to be understood by the policy making model users. The last point as well as much of this section may be summarized by the following quote from Ackoff (1970).

> Planning is the design of a desired future and of effective ways of bringing it about. It is an instrument that is used by the wise, but not by the wise alone. When conducted by lesser men it often becomes an irrelevant ritual that produces short-run peace of mind, but not the future that is longed for. (p. 1)

Recommendations

Model Related Research

Prior to full model implementation to a state's public postsecondary education system, a number of substudies are recommended. The substudies are as follows:

(1) The probable student demand relation should be tested for accuracy and for determining the effect of changing policies such as tuition rates, admissions standards, and student aid.

(2) Nonlinear cost and assignable square feet of space per FTE parameters should be derived that incorporate economies of scale relations into the model.

(3) Obtaining data for the student flow matrix should be made a routine procedure. The matrix should be tested for stability over time to determine its period of validity.

(4) A study must be undertaken to determine the extent to which model compatible manpower requirements forecasts exist.

(5) Modification of the linear programming model to a goal programming model should be investigated to increase the model's capacity to generate alternative futures due to changing policy scenarios.

Florida Community College Recommendations

During the period over which the research effort occurred, a number of system conditions were encountered that merit comment. Additionally, the model application to Florida community college registered nurse programs revealed that the direction programs were headed in 1980 would undoubtedly manifest manpower requirements problems in 1985. In sum, Florida community college recommendations are as follows:

(1) Accuracy of the Florida community college management information system should be improved by incorporating routine data collection and recording checks both at the state and institution level.

(2) Long range comprehensive system planning should become a meaningful and ongoing effort.

(3) If anticipated shortages of community college trained registered nurses are to be prevented in 1985, steps suggested by the model application segment should be of valuable assistance. If community colleges do not meet the challenge, the following consequences may be incurred (a) decreased health system quality with corresponding increased health service cost, (b) Florida will import nurses from elsewhere, and (c) other institutions, existing or newly created, will train nurses.

APPENDIX A
SUMMARY OF MODEL VARIABLES, DEFINING EQUATIONS, CONSTRAINT EQUATIONS, AND OBJECTIVE FUNCTION

Variables

a_{ij}	Number of assignable square feet of space required for instruction per FTE student in program j at institution i.
$a_{jk}(i,\ell)$	Participation rate of graduates from program j at institution i in occupation ℓ in county k.
A_{ij}	Total number of assignable square feet of space for program j at institution i for future time t.
c_{ij}	Cost per FTE student enrolled at institution i in program j in base year dollars.
C_{ij}	Total dollar allocation in base year dollars for program j at institution i for future time t.
d_ℓ	Annual net attrition rate for occupation ℓ.
α_i	Weighting factor for the double exponential smoothing forecast of program headcount enrollment for institution i for future time t.
F_i	Probable student demand in program FTE's for institution i for future time t.
K_i	Third level double exponential smoothing ratio of program FTE's to headcount for institution i for future time t.
G_{ij}	Number of anticipated graduates from program j at institution i for future time t.
H_i	Probable student demand by program headcount for institution i for future time t.
I_k	Anticipated need for public postsecondary education graduates for occupation ℓ in county k for future time t.

λ_i	Weighting factor for the ratio method forecast of program headcount enrollment for institution i for future time t.
m_ℓ	The average number of jobs per county in occupation ℓ filled by in-migrating workers for future time t.
a_ℓ	Fraction of jobs in occupation ℓ filled by public institution graduates for future time t
$O_{k\ell}$	Total additional manpower needs for occupation ℓ in county k for future time t.
P_{ij}	Number of FTE students enrolled at institution i in program j for future time t.
P_k'	Anticipated population of county k for future time t.
P_k	Population of county k in the base year.
r_{ij}	Ratio of the number of graduates from program j at institution i to the number of FTE students in program j at institution i for future time t.
R_i	Program headcount enrollment forecast for institution i by the ratio method for future time t.
s	First year in the base period.
t	Planning horizon year.
x	Number of years in the base period
X_i	Program headcount enrollment forecast for institution i by the double exponential smoothing technique for future time t.

Defining Equations

$$H_i = \frac{\lambda_i}{\lambda_i + \delta_i} R_i + \frac{\delta_i}{\lambda_i + \delta_i} \hat{X}_i \qquad (3.1)$$

$$P_i = g_i H_i \qquad (3.7)$$

$$G_{ij} = r_{ij} P_{ij} \qquad (3.15)$$

$$\sum_k O_{k\ell} = \frac{\sum_{m=s+x-1}^{t}\left(\sum_k O_{k\ell m}\right)}{(t-s-x+1)} + \frac{\sum_k O_{k\ell(s+x-1)} + \sum_k O_{k\ell t}}{2}\, d_\ell \,, \tag{3.16}$$

$$O_{k\ell} = \frac{1}{2}\left[\frac{P_k' - P_k}{\sum_k (P_k' - P_k)} + \frac{P_k'}{\sum_k P_k'}\right]\left(\sum_k O_{k\ell}\right) , \tag{3.17}$$

$$J_{k\ell} = (O_{k\ell} n_\ell) - m_\ell \,, \tag{3.18}$$

$$\sum_\ell \sum_k a_{jk}(i,\ell) \leq 1 \,, \tag{3.18}$$

Constraint Equations

$$\sum_j P_{ij} \leq F_i \tag{3.8}$$

$$P_{ij}c_{ij} \leq C_{ij} \tag{3.9}$$

$$\sum_j P_{ij}c_{ij} \leq \sum_j C_{ij} \tag{3.10}$$

$$\sum_i \sum_j P_{ij}c_{ij} \leq \sum_i \sum_j C_{ij} \tag{3.11}$$

$$P_{ij}a_{ij} \leq A_{ij} \qquad (3.12)$$

$$\sum_{j} P_{ij}a_{ij} \leq \sum_{j} A_{ij} \qquad (3.13)$$

$$\sum_{i} \sum_{j} P_{ij}a_{ij} \leq \sum_{i} \sum_{j} A_{ij} \qquad (3.14)$$

$$\sum_{i} \sum_{j} G_{ij}u_{jk}(i,\ell) \leq J_{k\ell} \qquad (3.20)$$

Objective Function

$$\max Z = \sum_{i} \sum_{j} P_{ij} \qquad (3.21)$$

APPENDIX E
FLORIDA COMMUNITY COLLEGE AND COUNTY KEY

Number	County	Community College
1	Alachua	Brevard
2	Bay	Broward
3	Brevard	Central Florida
4	Broward	Daytona Beach
5	Charlotte	Edison
6	Clay	Fla. J. C. at Jacksonville
7	Columbia	Florida Keys
8	Dade	Gulf Coast
9	Duval	Hillsborough
10	Escambia	Indian River
11	Hillsborough	Lake City
12	Indian River	Manatee Jr. College
13	Lake	Miami-Dade
14	Lee	Palm Beach Jr. College
15	Leon	Pasco-Hernando
16	Manatee	Pensacola Jr. College
17	Marion	Polk
18	Monroe	St. Petersburg Jr. College
19	Okaloosa	Santa Fe
20	Orange	Tallahassee
21	Palm Beach	Valencia
22	Pasco	
23	Pinellas	
24	Polk	
25	St. Lucie	
26	Sarasota	
27	Seminole	
28	Volusia	

APPENDIX C
PROGRAM AND COMPUTER OUTPUT FOR SERIES II BASELINE SCENARIO

Program Variable Key

Cnn	cost variables
Dnn	student demand variables
Snn	space variables
Rnn	requirements variables
Xnn	FTE enrollment variables

```
..MPSX-V1M7..  CONTROL PROGRAM COMPILER.  MPSX  RELEASE 1

              0091                    PROGRAM
              0092                    INITIALZ
              0096                    TITLE('MY DISSERTATION')
              0097                    MOVE(XDATA,'MAXIMIZE')
              0098                    MOVE(XPBNAME,'ARIZONA')
              0099                    CONVERT('CHECK','SUMMARY')
              0100                    BCDOUT
              0101                    SETUP('MAX')
              0102                    MOVE(XOBJ,'PTE')
              0103                    MOVE(XRHS,'CAPACITY')
              0104                    PICTURE
              0105                    CRASH
              0106                    PRIMAL
              0107                    SOLUTION
              0108                    EXIT
              0109                    PEND
 ..MPSX-V1M7..   MY DISSERTATION

 NAME            MAXIMIZE
 ROWS
  N  PTE
  L  D1
  L  D2
  L  D3
  L  D4
  L  D5
  L  D6
  L  D7
  L  D8
  L  D9
  L  D10
  L  D11
  L  D12
  L  D13
  L  D14
  L  D15
  L  D16
  L  D17
  L  D18
  L  D19
  L  D20
  L  D21
  L  S1
  L  S2
  L  S3
  L  S4
  L  S5
  L  S6
  L  S7
  L  S8
  L  S9
  L  S10
  L  S11
  L  S12
  L  S13
  L  S14
  L  S15
  L  S16
  L  S17
  L  S18
  L  S19
  L  S20
  L  S21
  L  C1
  L  C2
  L  C3
  L  C4
  L  C5
  L  C6
  L  C7
  L  C8
  L  C
```

```
..MPSX-V147..   MY DISSERTATION
 L   C10
 L   C11
 L   C12
 L   C13
 L   C14
 L   C15
 L   C16
 L   C17
 L   C18
 L   C19
 L   C20
 L   C21
 L   R1
 L   R2
 L   R3
 L   R4
 L   R5
 L   R6
 L   R7
 L   R8
 L   R9
 L   R10
 L   R11
 L   R12
 L   R13
 L   R14
 L   R15
 L   R16
 L   R17
 L   R18
 L   R19
 L   R20
 L   R21
 L   R22
 L   R23
 L   R24
 L   R25
 L   R26
 L   R27
 L   R28
COLUMNS
    X1        F-B               1.00000   T1              1.00000
    X1        S1              128.00000   C1           2250.00000
    X1        R1                 .00144   R2               .00144
    X1        R3                 .21628   R4               .00144
    X1        R5                 .00144   R6               .00144
    X1        R7                 .00144   R8               .00144
    X1        R9                 .00144   R10              .00144
    X1        R11                .00144   R12              .00144
    X1        R13                .00144   R14              .00144
    X1        R15                .00144   R16              .00144
    X1        R17                .00144   R19              .00144
    X1        R19                .00144   R20              .00144
    X1        R21                .00144   R22              .00144
```

```
APPENDIX .. [illegible]

    X1          R23         .00144   R24         .00144
    X1          R25         .00144   R26         .00144
    X1          R27         .00144   R28         .03600
    X2          FTE        1.00000   T2         1.00000
    X2          S2       138.00000   C2      3620.00000
    X2          R1          .00200   R2          .00200
    X2          R3          .00200   R4          .00200
    X2          R5          .00200   R6          .00200
    X2          R7          .00201   R8          .00200
    X2          R9          .00200   R10         .00200
    X2          R11         .00200   R12         .00200
    X2          R13         .00200   R14         .00200
    X2          R15         .00270   R16         .00200
    X2          R17         .00200   R18         .00200
    X2          R19         .00201   R20         .00200
    X2          R21         .00200   R22         .00200
    X2          R23         .02700   R24         .00200
    X2          R25         .00200   R26         .00200
    X2          R27         .00230   R28         .00200
    X3          FTE        1.00000   T3         1.00000
    X3          S3       132.00000   C3      3380.00000
    X3          R1          .00124   R2          .00124
    X3          R3          .00124   R4          .00124
    X3          R5          .00124   R6          .00124
    X3          R7          .00124   R8          .00124
    X3          R9          .00124   R10         .00124
    X3          R11         .03100   R12         .00124
    X3          R13         .02600   R14         .00124
    X3          R15         .00124   R16         .00124
    X3          R17         .07900   R18         .00124
    X3          R19         .00124   R20         .00124
    X3          R21         .00124   R22         .00124
    X3          R23         .00124   R24         .00124
    X3          R25         .00124   R26         .00124
    X3          R27         .00133   R28         .00124
    X4          FTE        1.00000   T4         1.00000
    X4          S4       133.00000   C4      2880.00000
    X4          R1          .00132   R2          .00132
    X4          R3          .00132   R4          .00132
    X4          R5          .00132   R6          .00132
    X4          R7          .00132   R8          .00132
    X4          R9          .00132   R10         .00132
    X4          R11         .00132   R12         .00132
    X4          R13         .00132   R14         .00132
    X4          R15         .00132   R16         .00132
    X4          R17         .00132   R18         .00132
    X4          R19         .00132   R20         .00132
    X4          R21         .00132   R22         .00132
    X4          R23         .00132   R24         .00132
    X4          R25         .00132   R26         .00132
    X4          R27         .09800   R28         .13200
    X5          FTE        1.00000   T5         1.00000
    X5          S5       129.00000   C5      1350.00000
    X5          R1          .00149   R2          .00148
```

```
**MPSX-V1M7**    MY DISSERTATION

      X5         R3             .00145    R4              .00148
      X5         R5             .00723    R6              .00148
      X5         R7             .00140    R8              .00148
      X5         R9             .00143    R10             .00148
      X5         R11            .00148    R12             .00148
      X5         R13            .00148    R14             .22200
      X5         R15            .00148    R16             .00148
      X5         R17            .00148    R18             .00148
      X5         R19            .00148    R20             .00148
      X5         R21            .00148    R22             .00148
      X5         R23            .00148    R24             .00148
      X5         R25            .00148    R26             .00148
      X5         R27            .00148    R28             .00148
      X6         RTE           1.00000    D6             1.00000
      X6         S6          138.00000    C6          3140.00000
      X6         R1             .00164    R2              .00164
      X6         R3             .00164    R4              .00164
      X6         R5             .00164    R6              .00164
      X6         R7             .00164    R8              .00184
      X6         R9             .24600    R10             .00164
      X6         R11            .00164    R12             .00164
      X6         R13            .00124    R14             .00164
      X6         R15            .00164    R16             .00184
      X6         R17            .00164    R18             .00104
      X6         R19            .00144    R20             .00164
      X6         R21            .04133    R22             .00184
      X6         R23            .00134    R24             .00184
      X6         R25            .00164    R26             .00164
      X6         R27            .00164    R28             .00154
      X7         RTE           1.00000    D7             1.00000
      X7         S7          138.00000    C7          4350.00000
      X7         R1             .00064    R2              .00084
      X7         R3             .00064    R4              .00064
      X7         R5             .00064    R6              .00064
      X7         R7             .00054    R8              .01600
      X7         R9             .00064    R10             .00064
      X7         R11            .00064    R12             .00064
      X7         R13            .00064    R14             .00064
      X7         R15            .00054    R16             .00064
      X7         R17            .00064    R18             .07800
      X7         R19            .00064    R20             .00064
      X7         R21            .00054    R22             .00084
      X7         R23            .00063    R24             .00084
      X7         R25            .00054    R26             .00384
      X7         R27            .00064    R28             .00064
      X8         RTE           1.00000    D8             1.00000
      X8         S8          138.00000    C8          3400.00000
      X8         R1             .00112    R2              .16800
      X8         R3             .00117    R4              .00112
      X8         R5             .00112    R6              .00112
      X8         R7             .00112    R8              .00112
      X8         R9             .00112    R10             .00112
      X8         R11            .00117    R12             .00117
      X8         R13            .00112    R14             .00112
```

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..MPSX-VIN?..   Y OBSERVATION

  X8        R15          .00112   R16          .00112
  X8        R17          .00112   R18          .00112
  X8        R19          .02800   R20          .00112
  X8        R21          .00112   R22          .00112
  X8        R23          .00112   R24          .00112
  X8        R25          .00112   R26          .00112
  X8        R27          .00112   R28          .00112
  X9        FREE        1.00000   D9          1.00000
  X9        S9        138.00000   C9       2940.00000
  X9        R1           .00104   R2           .00104
  X9        R3           .00104   R4           .00104
  X9        R5           .00104   R6           .00104
  X9        R7           .00104   R8           .00104
  X9        R9           .00104   R10          .00104
  X9        R11          .15600   R12          .00104
  X9        R13          .00104   R14          .00104
  X9        R15          .00104   R16          .00104
  X9        R17          .00104   R18          .00104
  X9        R19          .00104   R20          .00104
  X9        R21          .00104   R22          .00104
  X9        R23          .02600   R24          .00104
  X9        R25          .00104   R26          .00104
  X9        R27          .00104   R28          .00104
  X10       FREE        1.00000   D10         1.00000
  X10       S10       138.00000   C10      2773.00000
  X10       R1           .00168   R2           .00168
  X10       R3           .04200   R4           .00168
  X10       R5           .00168   R6           .00168
  X10       R7           .00168   R8           .00168
  X10       R9           .00168   R10          .00168
  X10       R11          .00168   R12          .12600
  X10       R13          .00168   R14          .00168
  X10       R15          .00168   R16          .00168
  X10       R17          .00168   R18          .00168
  X10       R19          .00168   R20          .00168
  X10       R21          .00168   R22          .00168
  X10       R23          .00168   R24          .00168
  X10       R25          .12600   R26          .00168
  X10       R27          .00168   R28          .00168
  X11       FREE        1.00000   D11         1.00000
  X11       S11       138.00000   C11      3010.00000
  X11       R1           .00124   R2           .00124
  X11       R3           .00124   R4           .00124
  X11       R5           .00124   R6           .06200
  X11       R7           .09200   R8           .00124
  X11       R9           .00120   R10          .00124
  X11       R11          .00124   R12          .00124
  X11       R13          .00124   R14          .00124
  X11       R15          .00122   R16          .00124
  X11       R17          .00124   R18          .00124
  X11       R19          .00124   R20          .00124
  X11       R21          .00124   R22          .00124
  X11       R23          .00124   R24          .00124
  X11       R25          .00124   R26          .00124
```

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..MPSX-VIN7..   [illegible]

    X11         R27              .00125    R28             .00125
    X12         FTT             1.00000    D12            1.00000
    X12         S12           138.00000    C12         7200.00000
    X12         R1               .00116    R2              .00116
    X12         R3               .00116    R4              .00116
    X12         R5               .00115    R6              .00115
    X12         R7               .00114    R8              .00116
    X12         R9               .00115    R10             .00116
    X12         R11              .00115    R12             .00116
    X12         R13              .00116    R14             .00116
    X12         R15              .00116    R16             .05800
    X12         R17              .00116    R18             .00115
    X12         R19              .00116    R20             .00116
    X12         R21              .00115    R22             .00116
    X12         R23              .02900    R24             .00116
    X12         R25              .00116    R26             .11600
    X12         R27              .00116    R28             .00116
    X13         FTT             1.00000    D13            1.00000
    X13         S13           139.00000    C13     [illegible].34000
    X13         R1               .00152    R2              .00172
    X13         R3               .00152    R4              .34700
    X13         R5               .00152    R6              .00152
    X13         R7               .00152    R8         [illegible]
    X13         R9               .00152    R10             .00152
    X13         R11              .00152    R12             .00152
    X13         R13              .00152    R14             .00192
    X13         R15              .00152    R16             .00172
    X13         R17              .00152    R18             .00172
    X13         R19              .00152    R20             .00192
    X13         R21              .00152    R22             .00192
    X13         R23              .00152    R24             .00152
    X13         R25              .00152    R26             .00152
    X13         R27              .00152    R28             .00152
    X14         FTT             1.00000    D14            1.00000
    X14         S14           138.00000    C14         3131.00000
    X14         R1               .00143    R2              .00143
    X14         R3               .00143    R4              .00143
    X14         R5               .00143    R6              .00143
    X14         R7               .00143    R8              .00777
    X14         R9               .00143    R10             .00143
    X14         R11              .00143    R12             .00143
    X14         R13              .00143    R14             .00143
    X14         R15              .00143    R16             .00143
    X14         R17              .00143    R18             .00143
    X14         R19              .00143    R20             .00143
    X14         R21              .22700    R22             .00143
    X14         R23              .00143    R24             .00143
    X14         R25              .00148    R26             .00143
    X14         R27              .00143    R28        [illegible]
    X15         FTT             1.00000    D15            1.00000
    X15         S15            25.00000    C15         3700.00000
    X15         R1               .00130    R2         [illegible]
    X15         R3               .00125    R4              .00125
    X15         R5               .00125    R6              .00125
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..MPSX-V1M2..   MY DISSERTATION
     X15          R7                 .00104   R9                  .00104
     X15          R9                 .00104   R10                 .00104
     X15          R11                .00104   R12                 .00104
     X15          R13                .00104   R14                 .00104
     X15          R15                .00104   R16                 .00104
     X15          R17                .00104   R18                 .00104
     X15          R19                .00104   R20                 .00104
     X15          R21                .00104   R22                 .10600
     X15          R23                .00104   R24                 .02600
     X15          R25                .00104   R26                 .00104
     X15          R27                .00106   R28                 .00104
     X16          FT16              1.00000   D16                1.00000
     X16          S16             126.00000   C16             3000.00000
     X16          R1                 .00148   R2                  .00148
     X16          R3                 .00148   R4                  .00148
     X16          R5                 .00148   R6                  .00148
     X16          R7                 .00148   R8                  .00148
     X16          R9                 .00148   R10                 .23200
     X16          R11                .00148   R12                 .00148
     X16          R13                .00148   R14                 .00148
     X16          R15                .00148   R16                 .00148
     X16          R17                .00148   R18                 .00148
     X16          R19                .03720   R20                 .00148
     X16          R21                .00148   R22                 .00148
     X16          R23                .00163   R24                 .00148
     X16          R25                .00148   R26                 .00148
     X16          R27                .00148   R28                 .00148
     X17          FT17              1.00000   D17                1.00000
     X17          S17             129.00000   C17             2730.00000
     X17          R1                 .00112   R2                  .00112
     X17          R3                 .00112   R4                  .00112
     X17          R5                 .00112   R6                  .00112
     X17          R7                 .00112   R8                  .00112
     X17          R9                 .00112   R10                 .00112
     X17          R11                .00112   R12                 .00112
     X17          R13                .00112   R14                 .00112
     X17          R15                .00112   R16                 .00112
     X17          R17                .00112   R18                 .00112
     X17          R19                .00112   R20                 .02800
     X17          R21                .00112   R22                 .00112
     X17          R23                .00112   R24                 .10800
     X17          R25                .00112   R26                 .00112
     X17          R27                .00112   R28                 .00112
     X18          FT18              1.00000   D18                1.00000
     X18          S18             129.00000   C18             2140.00000
     X18          R1                 .00124   R2                  .00124
     X18          R3                 .00124   R4                  .00124
     X18          R5                 .00124   R6                  .00124
     X18          R7                 .00124   R8                  .00124
     X18          R9                 .00124   R10                 .00124
     X18          R11                .00100   R12                 .00124
     X18          R13                .00124   R14                 .00124
     X18          R15                .00124   R16                 .00124
     X18          R17                .00124   R18                 .00124
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    Y DISSERTATION
    X19      R19          .00124    R20                 .00124
    X19      R21          .00124    R22                 .00124
    X19      R23          .18600    R24                 .00124
    X19      R25          .00124    R26                 .00124
    X19      R27          .00124    R28                 .00124
    X19      FTE         1.00000    D19                1.00000
    X19      S19       138.00000    C19             2990.00000
    X19      R1           .00080    R2                  .00080
    X19      R3           .00080    R4                  .00080
    X19      R5           .00080    R6                  .00080
    X19      R7           .00080    R8                  .02000
    X19      R9           .02000    R10                 .00080
    X19      R11          .02000    R12                 .00070
    X19      R13          .00080    R14                 .00080
    X19      R15          .00070    R16                 .00080
    X19      R17          .00080    R18                 .00070
    X19      R19          .00080    R20                 .00080
    X19      R21          .00090    R22                 .00060
    X19      R23          .00080    R24                 .00040
    X19      R25          .00040    R26                 .00080
    X19      R27          .00040    R28                 .00090
    X20      FTE         1.00000    D20                1.00000
    X20      S20       138.00000    C20             2980.00000
    X20      R1           .00156    R2                  .00156
    X20      R3           .00156    R4                  .00156
    X20      R5           .00156    R6                  .00156
    X20      R7           .00156    R8                  .00156
    X20      R9           .00920    R10                 .00156
    X20      R11          .00156    R12                 .00156
    X20      R13          .00156    R14                 .00156
    X20      R15          .20400    R16                 .00156
    X20      R17          .00156    R18                 .00156
    X20      R19          .00156    R20                 .00156
    X20      R21          .00156    R22                 .00156
    X20      R23          .00156    R24                 .00156
    X20      R25          .00156    R26                 .00156
    X20      R27          .00156    R28                 .00156
    X21      FTE         1.00000    D21                1.00000
    X21      S21       138.00000    C21             3720.00000
    X21      R1           .00143    R2                  .00143
    X21      R3           .22700    R4                  .00148
    X21      R5           .00148    R6                  .00149
    X21      R7           .00143    R8                  .00148
    X21      R9           .00148    R10                 .00143
    X21      R11          .00148    R12                 .00148
    X21      R13          .00148    R14                 .00148
    X21      R15          .00148    R16                 .00148
    X21      R17          .00149    R18                 .00145
    X21      R19          .00148    R20                 .22900
    X21      R21          .00149    R22                 .00148
    X21      R23          .00144    R24                 .00143
    X21      R25          .00144    R26                 .00149
    X21      R27          .00148    R28                 .00144
RHS
```

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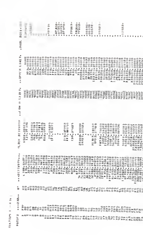
••MPSX-V1M7••   MY DISSERTATION

     CAPACITY  D1           712.00000   D2           323.00000
     CAPACITY  D3           255.00000   D4           471.00000
     CAPACITY  D5           239.00000   D6           809.00000
     CAPACITY  D7           146.00000   D8           275.00000
     CAPACITY  D9           608.00000   D10          149.00000
     CAPACITY  D11          171.00000   D12          418.00000
     CAPACITY  D13          555.00000   D14          479.00000
     CAPACITY  D15          123.00000   D16          521.00000
     CAPACITY  D17          441.00000   D18          707.00000
     CAPACITY  D19          633.00000   D20           96.00000
     CAPACITY  D21          117.00000   S1         46400.00000
     CAPACITY  S2         63400.00000   S3         23700.00000
     CAPACITY  S4         91500.00000   S5         23700.00000
     CAPACITY  S6        120700.00000   S7         11100.00000
     CAPACITY  S8         14500.00000   S9        100200.0000
     CAPACITY  S10        12600.00000   S11        21600.00000
     CAPACITY  S12        87200.00000   S13       137500.0000
     CAPACITY  S14       120200.00000   S15        25300.00000
     CAPACITY  S16        67800.00000   S17        44600.00000
     CAPACITY  S18       140500.00000   S19       115600.0000
     CAPACITY  S20        17900.00000   S21       149500.0000
     CAPACITY  C1       3000000.000     C2       3300000.000
     CAPACITY  C3       3000000.000     C4       3300000.000
     CAPACITY  C5       3000000.000     C6       3300000.000
     CAPACITY  C7       3000000.000     C8       3300000.000
     CAPACITY  C9       3000000.000     C10      3300000.000
     CAPACITY  C11      3000000.000     C12      3300000.000
     CAPACITY  C13      3000000.000     C14      3300000.000
     CAPACITY  C15      3000000.000     C16      3300000.000
     CAPACITY  C17      3000000.000     C18      3300000.000
     CAPACITY  C19      3000000.000     C20      3300000.000
     CAPACITY  C21      3000000.000     E1            48.00000
     CAPACITY  E2            35.00000   E3            67.00000
     CAPACITY  E4           263.00000   E5            30.00000
     CAPACITY  E6            70.00000   E7            14.00000
     CAPACITY  E8           376.00000   E9           117.00000
     CAPACITY  E10           58.00000   E11          153.00000
     CAPACITY  E12           25.00000   E13           38.00000
     CAPACITY  E14           87.00000   E15           47.00000
     CAPACITY  E16           53.00000   E17           45.00000
     CAPACITY  E18           16.00000   E19           37.00000
     CAPACITY  E20          129.00000   E21          217.00000
     CAPACITY  E22           62.00000   E23          243.00000
     CAPACITY  E24           74.00000   E25           37.00000
     CAPACITY  E26           78.00000   E27           78.00000
     CAPACITY  E28           83.00000
ENDATA
```



NUP [illegible] [illegible] [illegible] ACTIVITY LACK ACTIVITY [illegible] LIMIT UPPER LIMIT REAL ACTIVITY

NUMBER	.COLUMN.	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT.	..UPPER LIMIT.	.REDUCED COST.
1	X1	BS	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
[illegible]	[illegible]	[illegible]	[illegible]	1.00000	.	NONE	.
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BIOGRAPHICAL SKETCH

Thomas Alan Gaylord was born October 27, 1953, in St. Paul, Minnesota. He graduated from South St. Paul Senior High School in 1972 where he was active in student organizations and athletics. In 1972, Tom was President of the Minnesota Junior Academy of Science. That fall, he matriculated at Luther College in Decorah, Iowa. In 1975, he transferred to the University of Alaska in Fairbanks. He was honored as the outstanding physics student in 1976 by the faculty and was also nominated to Phi Kappa Phi. He graduated with a B.S. degree in physics in 1976.

The summers from 1973 through 1975, Tom worked for Wakefield Seafoods in Sand Point, Alaska. In 1976, he worked for the Alaska Department of Fish and Game collecting data on the salmon run in the Shumagin Islands and Bristol Bay areas.

In 1976, Tom entered graduate school at the University of Florida and received the M.S.T. degree in physics in 1977. He entered the doctoral program in educational administration in 1978.

Tom was a graduate instructor in physics and meteorology for two years at Florida. He was a graduate research assistant for the Florida Community Junior College Inter-institutional Research Council, the Department of Educational

Administration, and the Florida Institute for Educational Linkage Development. He interned at Santa Fe Community College and at the University of Florida's Division of Planning and Analysis.

Thomas Alan Gaylord is married to the former Lorrinda Gail Galovin of Sand Point, Alaska. He is a member of the Association for Institutional Research, Phi Delta Kappa, and the World Future Society.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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